REFINER
AND NATURAL GASOLINE MANUFACTURER

MAY, 1939
Vol. 18, No. 5

A Gulf Publishing Company Publication
EDITED MONTHLY AT HOUSTON, TEXAS

GEORGE REID
Editor

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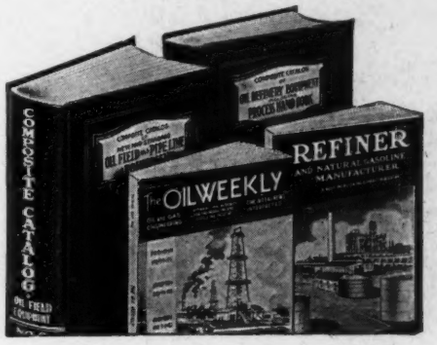

SPECIALIZED OIL JOURNALS

Published by

THE GULF PUBLISHING COMPANY

OFFICE OF PUBLICATION
3301 Buffalo Drive, Houston, Texas

R. L. DUDLEY, *President*
A. L. BURNS, *General Manager*
S. W. ROBINSON, *Editorial Director*
J. KENT RIDLEY, *Managing Editor*

NEW YORK: Room 625, 250 Park Avenue, Dick Swinsky, Manager.

PITTSBURGH: 72 Vandergrift Building, Chas. A. Wardley, Manager.

CHICAGO: 332 S. Michigan Avenue, H. G. Fitzpatrick, Manager.

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TULSA: 1513 Hunt Building, J. F. Carter, Jr., Manager.

FT. WORTH: 203 W. T. Waggoner Building, H. H. King, Manager.

Single copies 20 cents. Domestic subscription price $1.00 a year. Canada and Foreign subscription price $2.00 a year. Entered as second class matter June 16, 1923, at the post office at Houston, Texas under act of March 3, 1879. Advertising rates on application.

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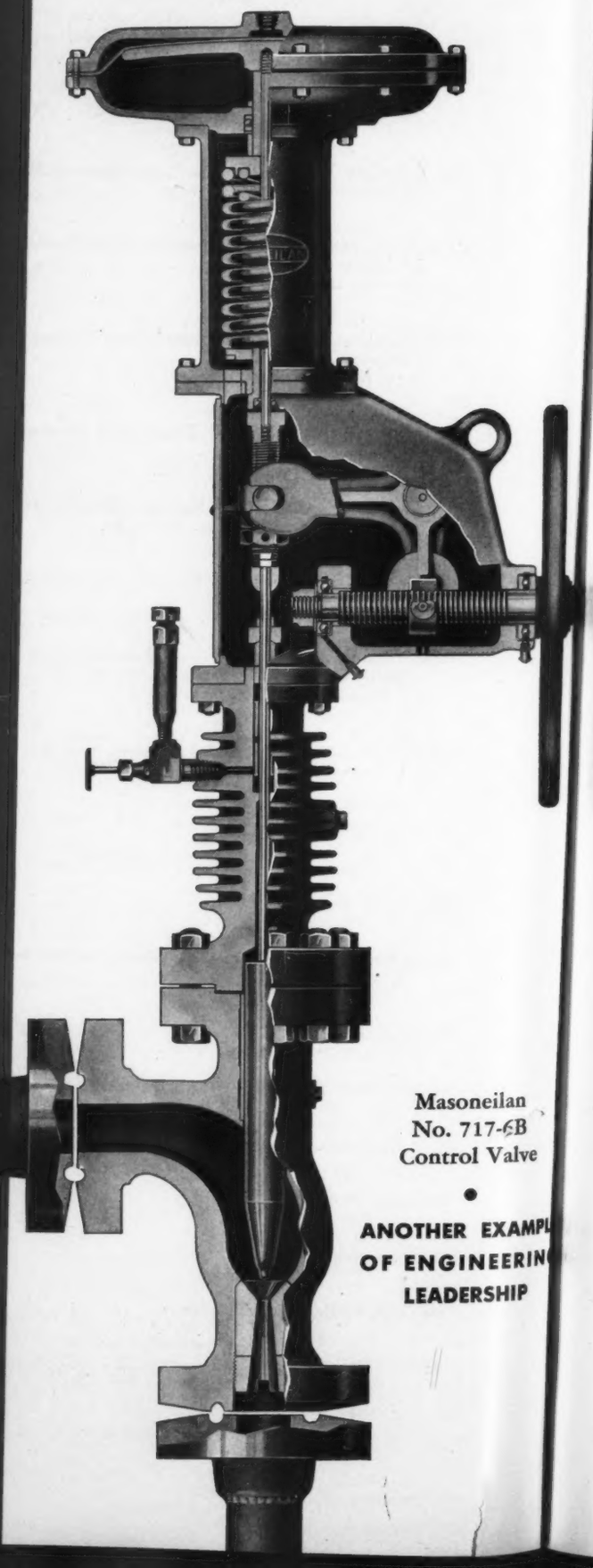

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ANOTHER EXAMPL
OF ENGINEERIN
LEADERSHIP

The Solutizer Process *for the Extraction of* Mercaptans

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and
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THE addition of suitable organic solvents or salts to an aqueous caustic solution imparts peculiar solvent properties to the resulting "solutized" solution, and leads to a greatly-enhanced removal of mercaptans from gasolines. Most gasolines can be sweetned realiy by extraction with such solutized solutions, and the results of a pilot-plant study are described. Solutizer sweetening results, in many cases, in an attractive improvement in both the initial octane number of the gasoline and its lead susceptibility. The process has reached the stage, both in the laboratory and in the pilot plant, where it is ready for commercial application.

This paper was presented at Ninth Mid-Year Meeting, American Petroleum Institute, at the Roosevelt Hotel, New Orleans, May 18, 1939.

IT IS desirable to remove mercaptans completely from gasolines by extraction rather than to convert them to disulfides. Aside from a reduction in the total sulfur content of the gasoline, the most important effect is an improvement both in the initial octane number and in the lead susceptibility, as disclosed recently in the literature.[1a] In addition, improved light stability and inhibitor susceptibility may be expected in many cases.

Only partial mercaptan removal can be obtained by using aqueous caustic solutions, inasmuch as the heavier mercaptans are very difficult to extract. The degree of mercaptan removal can be improved somewhat by increasing the caustic concentration up to a certain point, but thereafter there is no improvement, and the extraction actually may become poorer. In a previous paper[2] it was shown that the extent of removal of a mercaptan from an oil phase by an aqueous alkaline solution is a function of the ionization constant of the mercaptan and of the relative solubility of the *unneutralized* mercaptan in the aqueous alkaline phase. As might be expected by analogy with other homologous series of acids, the ionization constants of the mercaptans are not affected greatly by an increase in the molecular weight, but the water solubility of the mercaptan is reduced markedly. It was shown further that sodium hydroxide acts to salt out the unneutralized mercaptan from the aqueous phase, and this effect is greater for the heavier than for the lighter mercaptans. Our failure, then, to achieve complete extraction of mercaptans from gasolines using aqueous caustic solutions is due mainly to the poor water solubility of the heavier mercaptans, and this is magnified by the salting-out effect of the sodium hydroxide.

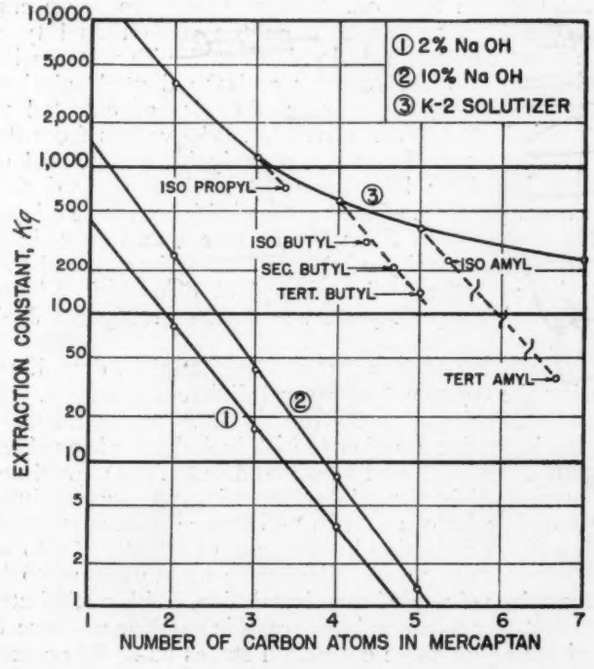

FIGURE 1

Extraction of a Series of Pure Mercaptans from Iso-octane at 20° C. with Aqueous Alkaline Solutions

PRINCIPLE OF THE SOLUTIZER PROCESS

As a result of the above considerations, a rather extensive study was undertaken, and it was found that the addition of suitable organic solvents or salts ("solutizers") to an aqueous alkaline solution increased the solubility of the resulting solution for mercaptans, and led to greatly-enhanced extraction results. This is illustrated by the data in Figure 1, which shows the extraction of a series of pure mercaptans from *iso*octane at 20° C., using aqueous caustic solutions and a "solutized" caustic solution. The results are expressed in terms of the extraction constant, Kq, which is defined

$$\frac{\text{mercaptan concentration in the aqueous phase}}{\text{mercaptan concentration in the oil phase}}$$

It is obvious, of course, that the higher the Kq values, the better will be the removal of the mercaptans from the oil phase under a given set of conditions.

Referring now to Figure 1, it is noted that the extraction constant drops off exponentially with an increase in the number of carbon atoms in the mercaptan for the

aqueous caustic solutions (curves 1 and 2.). The relatively small improvement obtained by increasing the sodium-hydroxide concentration also is apparent. The use of potassium hydroxide instead of sodium hydroxide gives slightly better results, but the magnitude is not affected. Curve 3 of Figure 1 is for one of the better solutizer solutions. This curve is not linear, as was the case for the aqueous caustic solutions; and the extraction constants decrease quite slowly in the region of the heavier mercaptans. The dotted lines leaving the main curve show the regular relation between the branching of a mercaptan of a given molecular weight and its extraction constant. The improvement brought about by the solutizer is very much greater for the heavier mercaptans than for the lighter ones. It may be noted, in passing, that the extraction constant for *n*heptyl mercaptan with the solutized solution is the same as that for ethyl mercaptan with 10 percent aqueous sodium hydroxide.

NECESSARY PROPERTIES OF A SOLUTIZER

A large number of materials have been tested as solutizers, among which were alcohols, glycols, glycol ethers, alkanolamines, alkylene diamines, diamino alcohols, quaternary ammonium hydroxides, ternary sulfonium hydroxides, salts of organic acids, and many other compounds. Some of these materials enhanced greatly the extraction of mercaptans when added to aqueous alkaline solutions, whereas the effect of others was comparatively small. In addition to improving the extracting power of the aqueous alkaline solution to which it is added, a solutizer must meet the following specifications in addition if it is to be of practical commercial use.

1. The solutizer should be very soluble in the aqueous caustic phase, and only slightly soluble in the gasoline. The small amount dissolved in the treated gasoline should be readily recoverable in some simple manner such as by water-washing the gasoline.
2. The vapor pressure of the solutizer at elevated temperatures should be low in comparison to that of water, inasmuch as the spent solutized caustic solution is to be regenerated by stripping with steam, a method which has been applied successfully on a commercial scale with ordinary caustic solutions.
3. It goes without saying, of course, that the solutizer must not be decomposed nor changed in either cold or hot alkaline solutions.

Of the large number of materials tested as solutizers, several are suitable for commercial-scale operation; and of these, the salt of *iso*butyric acid is a stand-out. Either the sodium or the potassium salt may be used in aqueous solutions together with the corresponding hydroxide, but the potassium solutizer appears to be more universally applicable to different gasolines, and is preferred for this reason. Typical compositions of the solutions employed are from 4 to 6 normal in free hydroxide together with about 3 normal *iso*butyrate salt.

PILOT-PLANT STUDIES OF THE *ISO*BUTYRATE SOLUTIZER

From the laboratory stage, the process went to a small continuous metal treater, where several solutizers were tested and the superiority of the *iso*butyrate solutizer confirmed. Following this, a pilot plant was built to treat about 250 barrels of gasoline per day—with the following objectives in mind:

1. To study the continuous operation of the process in order to discover and iron out any "bugs" which may have been overlooked in the laboratory and small continuous-treater stage.
2. To study the treatment of several gasolines of different types.
3. To obtain data for the design and operation of a commercial installation. This step consists, to a certain extent, in checking and extending theoretical calculations which have been made by the method described in the previous papers[2], and which have indicated clearly the direction of the optimum design and operating conditions.

A simplified flow diagram of the pilot plant is given in Figure 2. Essentially, the gasoline first is scrubbed with a dilute sodium-hydroxide or tripotassium-phosphate solution to remove any hydrogen sulfide and/or fatty acids, and then is contacted countercurrently with

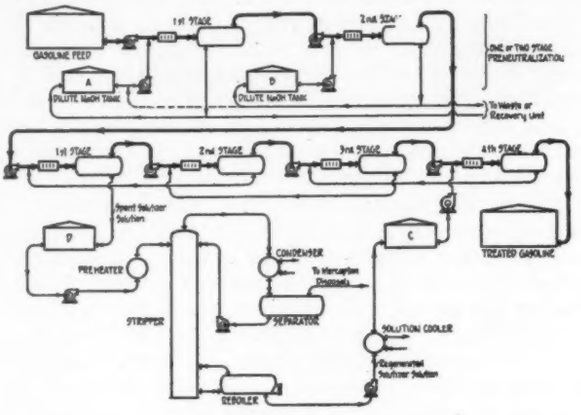

FIGURE 2
Simplified Flow Diagram of the Solutizer Pilot Plant

a regenerated solutizer solution in four stages consisting of separate mixers and settlers. The spent solutizer solution passes to a stripping column, and flows countercurrent to the ascending steam; and in this operation the mercaptides are hydrolyzed and stripped from the solutizer solution. It may be noted here that 100 percent regeneration of the solutizer solution is not required, even when producing a doctor-sweet gasoline. However, only a certain definite quantity of mercaptides may be tolerated in the regenerated solution, and this amount depends largely on the type of mercaptides present, as will be shown later on. The stripping procedure employed differs somewhat from the conventional type. The spent solutizer solution is diluted with water prior to its entry to the column; and the diluted solution, after descending the column, then is concentrated to its original strength in a reboiler. The vapors from the reboiler serve as the source of stripping steam. Calculations based on laboratory data, which showed that the vapor pressure of mercaptans is higher above diluted solutizer solutions than above concentrated ones, indicated the superiority of this type of stripping, and this has been confirmed by pilot-plant operation. Photographs of the pilot plant are shown in Figures 3, 4, and 5.

Table 1 summarizes part of the pilot-plant data, illustrating the treatment of several different gasolines. It will be noted that a 95 to 250° F. (approximately) cracked-gasoline fraction (which had already been given a plant soda treatment and then debutanized) could not be sweetened in the pilot plant using aqueous sodium-hydroxide solutions of 15 to 45 degree Baume strength (item 1). A reduction in mercaptan content of 80 to 90 percent was the best obtained, even when using up to 40 percent by volume of caustic solution. With an *iso*butyrate solutizer solution, however, this gasoline was sweetened readily in three extraction stages using 20 percent by volume of solution (item 2). The same gasoline prior to the plant soda treatment and debutanizing contained about 0.17 percent mercaptan sulfur. It also was sweet-

TABLE 1

Summary of Pilot-Plant Data (Unless Otherwise Noted) for the Extraction of Mercaptans from Gasolines with Caustic Solutions

Item No.	Gasoline	Caustic Solution	Volume Ratio of Caustic Solution to Gasoline in Extraction System	Steam Used for Regeneration (Lbs. per Gallon of Caustic Solution)*	Mercaptan Sulfur in Gasoline		Percentage of Total Mercaptans Extracted from Gasoline	Mercaptan Sulfur in Caustic Solution		Remarks
					Before Treatment	After Treatment		Spent Solution (at Equilibrium) (Percent)	Regenerated Solution (at Equilibrium) (Percent)	
					Percent					
1	95° to 250° F. (approximately) cracked (plant soda-treated and debutanized).	15° to 45° Baume aqueous NaOH.	0.2-0.4	5-10	0.045	0.005 0.009	80-90	0.09	0.01 and less	.....
2	Same as item (1).....	4.7N KOH-3N KIB	0.2	5	0.045	Doctor sweet	99 (approx.)	0.13	0.02	Gasoline sweet after three extraction stages.
3	Item (1) before plant soda-treating and debutanizing.†	Same as item (2).	0.2	5	0.17	Doctor sweet	99.5 (+)	0.91	0.55	Gasoline sweet after two to four stages.
4	90° to 200° F. (approximately) mixed straight-run.	Same as item (2).	0.2 and 0.3	5	0.05	Doctor sweet	99 (approx.)	0.25-0.30	0.10-0.15	Gasoline sweet after three to four stages.
5	400° F.-end-point West-Texas straight-run.	Same as item (2).	0.3	5-10	0.065	0.015	77	0.11	0.032	.....
6‡	Same as item (5).....	15° Baume aqueous NaOH.	0.3	....	0.076 0.076	0.070 0.069	8 9 (+)	....	....	Three stages.‡ Six stages.‡

* In lieu steam for pre-heating. †Contains about 50 percent butanes. ‡ Laboratory countercurrent treater.

ened readily with solutizer under the same conditions after two to four stages of extraction (item 3). Of interest is the high mercaptide content of the regenerated solution in this case, viz., 0.55 percent sulfur. These undoubtedly are the lower mercaptides, and appreciable amounts of them may be tolerated in the regenerated solution as illustrated by this example. No particular difficulty was encountered in sweetening a 90 to 200° F. mixed straight-run fraction containing 0.05 percent mercaptan sulfur (item 4), but a full-range West Texas

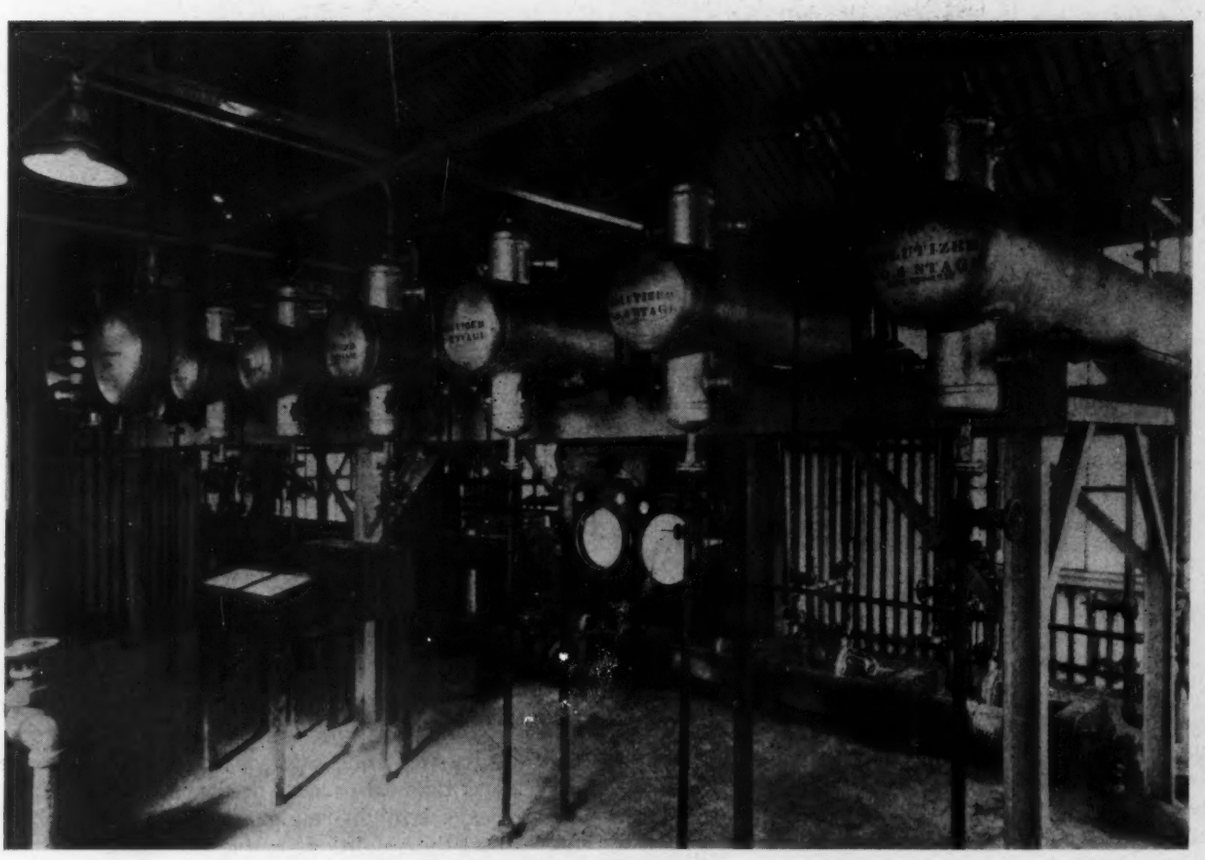

FIGURE 3

Pre-neutralizing and Extraction Section of the Solutizer Pilot Plant

The two larger vessels at the extreme left are surge tanks for the spent and regenerated solutizer solutions. Mixers and interstage transfer pumps are seen below in the rear.

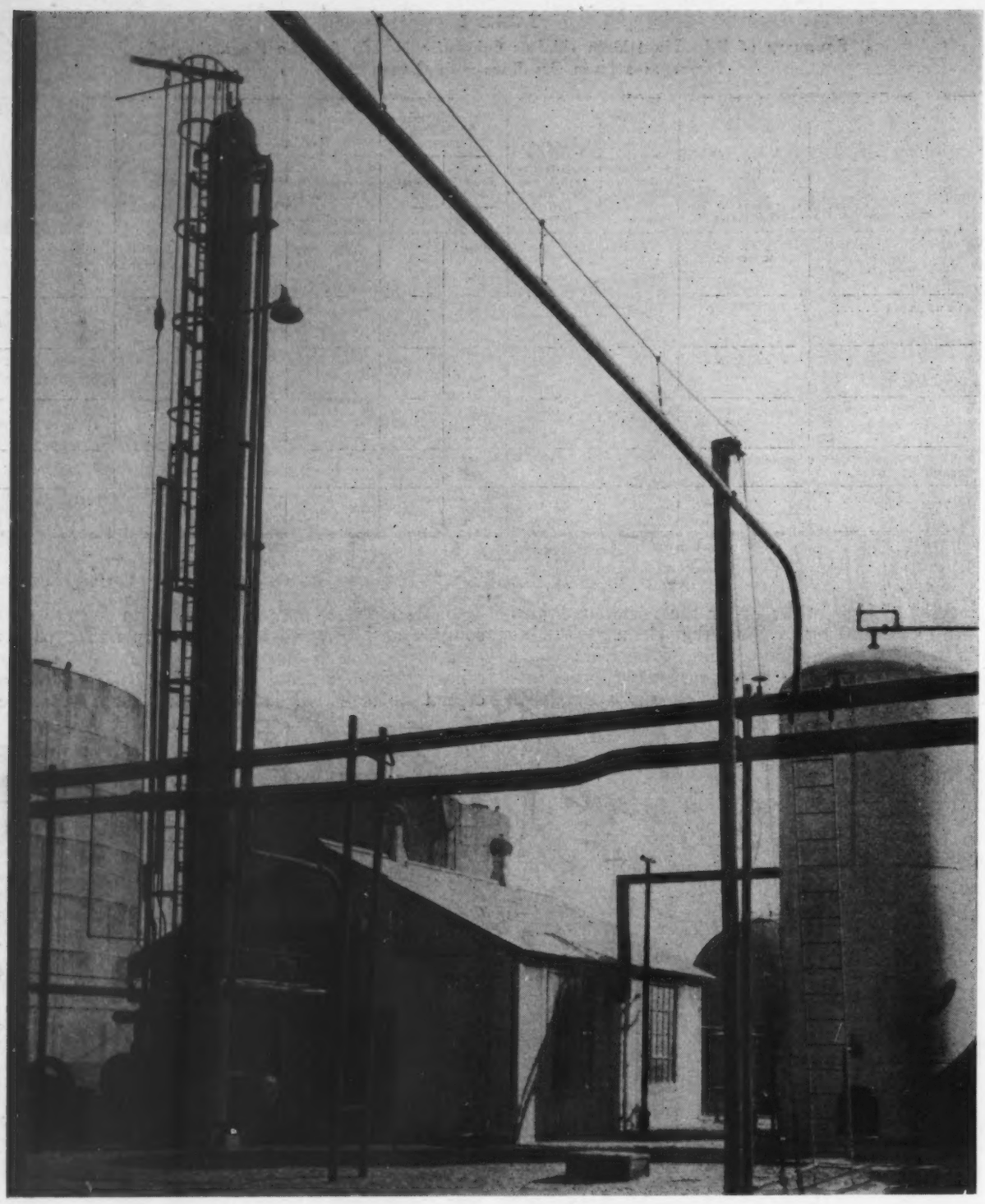

FIGURE 4
Stripping Column of the Solutizer Pilot Plant
The building houses, the extraction section, and the pumps.

straight-run gasoline containing 0.065 percent mercaptan sulfur could not be sweetened under the conditions employed—some 77 percent only of the mercaptans having been removed from the gasoline (item 5). Sweetening of this stock no doubt could be achieved in several ways:

1. By circulating more solutizer solution.
2. By use of more extraction stages.
3. By blending the straight-run gasoline prior to treatment into another material containing mainly the lighter mercaptans.

For comparison, data from laboratory countercurrent extractions are included in Table 1 (item 6) showing that 15-degree-Baume aqueous sodium hydroxide removes less than 10 percent of the mercaptans from the West Texas straight-run gasoline. It should be mentioned that the conditions employed in the pilot plant in making the above runs were not necessarily the optimum with regard to economy, inasmuch as it was desired mainly in this part of the study to observe the continuous treatment of several different gasolines.

Marked corrosion was observed in the steel tubes of the stripping-column reboiler, and this was found to be the usual caustic embrittlement by a metallographic investigation. This difficulty now has been overcome by substituting copper-nickel alloy tubes in the reboiler. Metal samples were taken throughout the rest of the pilot plant as well, and subjected to a careful metallographic examination; and it was found that corrosion was confined almost entirely to the reboiler tubes. The pilot-plant study has disclosed several points of possible

TABLE 2
Effect of Sweetening Treatments on Octane Number and Lead Susceptibility

Item No.	Gasoline	Treatment	ASTM Octane Number				
			Unleaded	Plus 1 Ml. Tetraethyl Lead	Plus 1½ Ml. Tetraethyl Lead	Plus 2 Ml. Tetraethyl Lead	Plus 3 Ml. Tetraethyl Lead
1	Full-range cracked—debutanized....	Plant doctor-sweetened	70.6	74.9	....	77.0	78.6
		Laboratory copper-sweetened	71.4	75.2	....	77.4	79.1
		Laboratory solutizer-sweetened	71.6	75.5	....	78.0	79.4
2	300° F.-end-point cracked—debutanized.	Sour—0.04 percent mercaptan sulfur	74.0	....	....	....	....
		Laboratory doctor-sweetened	72.8	....	....	....	....
		Plant doctor-sweetened	72.7	....	....	....	....
		Laboratory solutizer-sweetened	73.9	....	....	....	....
3	90 to 200° F. mixed stright-run.....	Sour—0.05 percent mercaptan sulfur	73.0	79.5	....	83.0	....
		Pilot-plant solutizer sweetened	74.0	81.5	....	85.0	....
4	90 to 200° F. mixed straight-run.....	Sour—0.05 percent mercaptan sulfur	72.0	....	81.0	....	84.0
		Pilot-plant solutizer-sweetened	....	....	83.0	....	87.0
		Laboratory copper-sweetened	....	....	80.5	....	83.5
5	Full-range West-Texas straight-run..	Sour—0.08 percent mercaptan sulfur	52.0	59.5	....	64.5	69.5
		Pilot-plant solutizer-treated—0.017 percent mercaptan sulfur	52.0	61.0	....	65.5	70.0
		Laboratory copper-sweetened	51.5	59.0	....	64.0	67.5
6	126 to 292° F. straight-run (aviation stock).	Sour—total sulfur=0.09 (9) percent; mercaptan sulfur=0.056 percent	68.2	75.6	....	....	82.7
		Laboratory solutizer-sweetened—total sulfur=0.04 (8) percent	68.6	79.3	....	....	86.2

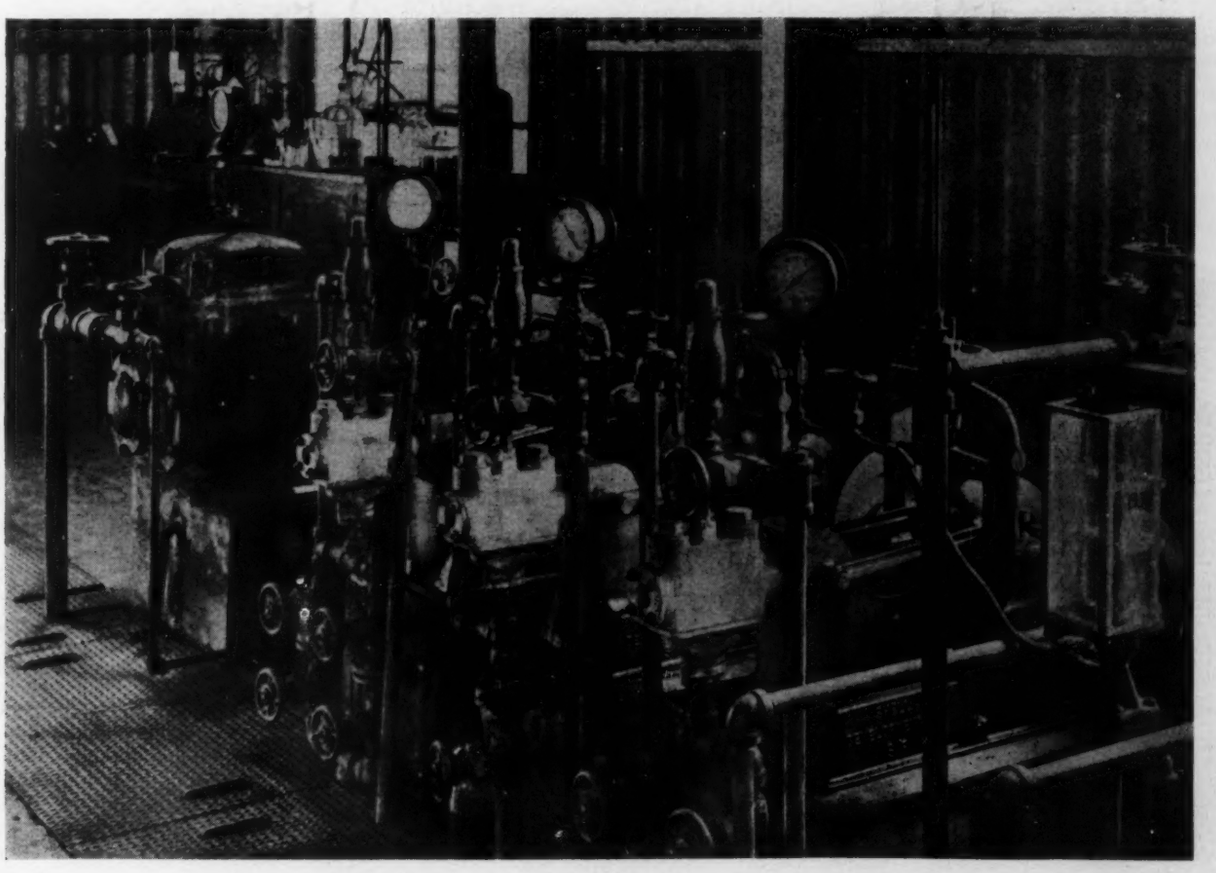

FIGURE 5

Charging Pumps of the Solutizer Pilot Plant

These pumps are, left to right:
a. Treated gasoline pump—(to storage).
b. Regenerated solutizer pump—(to last stage of extraction section).
c. Dilute-soda pump—(to pre-neutralizing section).
d. Spent-solutizer pump—(to stripping column).
e. Gasoline-feed pump—(to pre-neutralizing section).

TABLE 3

Lead Requirements for Variously-sweetened Gasolines

Item No.	Gasoline	Treatment	Milliliters of Tetraethyl Lead Per Gallon Required for the Following Octane Numbers						
			65	70	73	77	80	83	87
1	Full-range cracked—debutanized.	Plant doctor-sweetened	....	....	0.38	1.90	....	....	....
		Laboratory copper-sewetened	....	....	0.23	1.70	....	....	....
		Laboratory solutizer-sweetened	....	....	0.16	1.46	....	....	....
3	90 to 200 °F. mixed straight-run.	Sour—0.05 percent mercaptan sulfur	....	....	....	0.40	1.03	2.22	5.40
		Pilot-plant solutizer-sweetened	....	....	....	0.22	0.61	1.40	3.25
4	90 to 200 °F. mixed straight-run.	Sour—0.05 percent mercaptan sulfur	....	....	....	0.53	1.20	2.40	5.60
		Laboratory copper-sweetened†	....	....	....	0.57	1.32	2.75	>6
		Pilot-plant solutizer-sweetened†	....	....	....	0.37	0.78	1.50	3.10
5	Full-range West-Texas straight-run.	Sour—0.08 percent mercaptan sulfur	2.13	4.20	*	....	....	....	....
		Laboratory copper-sweetened	2.32	4.65	*	....	....	....	....
		Pilot-plant solutizer-treated—0.017 percent mercaptan sulfur	1.75	3.50	....	....	....	....	....
6	126 to 292 °F. straight-run (aviation stock).	Sour—total sulfur=0.09 (9) percent; mercaptan sulfur=0.056 percent	....	....	0.42	1.14	1.96	3.60	>6
		Laboratory solutizer-sweetened—total sulfur=0.048 percent	....	....	0.23	0.64	1.10	1.80	3.35

* Leaded octane-number points plotted quite poorly.
† The initial octane number of the sweetened samples was assumed to be the same as that for the sour sample.

improvement of a rather minor nature, and has indicated clearly that full-scale operation will lead to no particular difficulties when using a "solutized" caustic solution instead of an ordinary aqueous caustic solution.

The pilot plant now is being employed to obtain more precise data on such factors, for example, as the minimum stripping-steam requirement as a function of other variables such as the volume of caustic solution circulated in the extraction system, the number of stripping plates, etc. Theoretical calculations have been made already along such lines; and the pilot-plant work, although not complete in all details, appears to confirm these calculations rather well. It may be of interest to show a relation which was calculated for the sweetening of a very sour cracked-gasoline fraction containing 0.36 percent mercaptan sulfur, labelled gasoline A in Figure 6. It is indicated that appreciable savings in steam may be realized by reducing the volume of solutizer solution circulated. This can be achieved as well by circulating a larger volume, but of a more dilute solutizer solution. Of interest also is the fact that very little saving in steam can be obtained by increasing the number of theoretical stripping plates beyond about 10. The slope and magnitude of such stripping curves depend on the type and quantity of the mercaptans initially present in the gasoline. This is illustrated also in Figure 6 for gasoline B, which contains only 0.055 percent mercaptan sulfur initially.

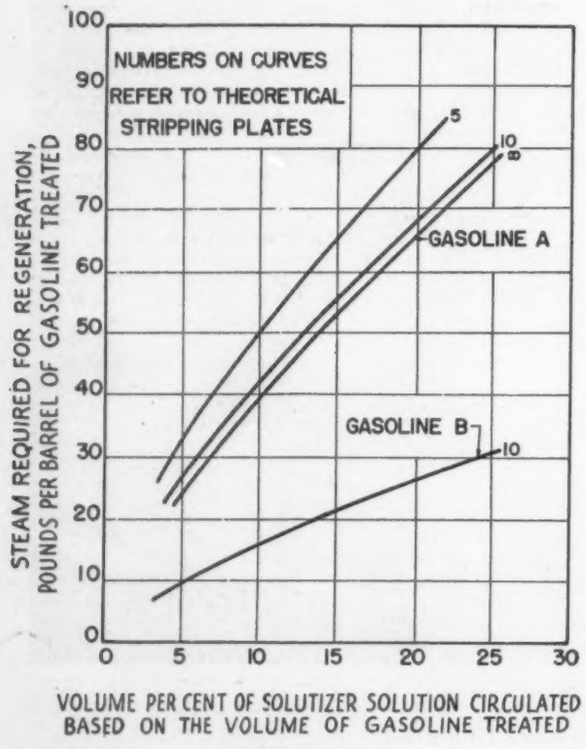

FIGURE 6

Theoretical Steam Requirements for Regenerating the Spent Solutizer When Producing a Doctor-Sweet Gasoline.

EFFECT OF SOLUTIZER SWEETENING ON GASOLINE PROPERTIES

The effect of solutizer sweetening on the octane number and lead susceptibility is illustrated by the data of Table 2. The data may be summarized by saying that solutizer treatment either does not change, or improves by as much as one unit, the octane number of the unleaded gasoline in comparison to the sour stock; and in this respect it is superior to other sweetening methods. In addition, a marked improvement in lead susceptibility usually results. This is shown in Table 3, where the data of the preceding table have been expressed as the amount of tetraethyl lead required to reach different octane numbers. The extent of the improvement in initial octane number and lead susceptibility resulting from solutizer sweetening must depend, to a considerable extent, on the prior treatment of the gasoline and on the amount and nature of the non-mercaptan-sulfur compounds present.

The solutized solutions are such efficient extractants that they remove completely not only the mercaptans from the gasoline, but the alkyl phenols as well. This *complete* removal of alkyl phenols is not desirable, because they function as oxidation inhibitors, and the stripped gasoline may be left very unstable with respect to gum formation. The astonishing extent to which a cracked gasoline depends on inhibitors for its stability, even a gasoline which has been well acid-treated, has not been realized previously. This fact has been overlooked, because truly "uninhibited" cracked gasolines probably have not been obtained before. It is not possible to remove the natural inhibitors completely by exhaustive treatment with aqueous caustic solutions,

(*Continued on page 203*)

Laboratory Method for
Indicating Road Performance
of Motor Fuels

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Philadelphia, Pennsylvania

A LABORATORY method has been developed that, according to about two years of operating experience, appears to indicate fairly satisfactorily the expected average road performance of motor fuels. Endeavor has been made to develop a method that involves a test as much on fuels and as little on engine variables as possible. It was concluded that the main difficulty with previously-proposed laboratory methods lies in the time element for loading the engine and picking up speed; that it should be feasible to operate with standard multi-cylinder engines under controlled physical conditions with inertia loading as afforded by a flywheel of required weight and design; so that a time interval of about 90 seconds is involved in loading within the range of speeds of interest; so that the observations can be made of the knocking characteristics on the fuel. We designate the method as the AIL test (acceleration-inertia-load).

For fairly closely standardized semi-routine operation for control purposes, full details of operation are outlined in the paper, with suggestions for variations for application for more general studies on variations in conditions and fuels. Drawings and photographs of the unit, with suggestions for possible further improvements and economies in design, are presented.

Summary is presented of some comparative results from AIL, road, and standard-laboratory single-cylinder-engine tests.

According to results from a large number of samples tested by this method for series involving determinations by engines of the three most widely distributed makes of cars, reproducibility of results by our own laboratories under the specified conditions of test appear to be within a limit of error of ± 1 octane number.

This paper was presented at Ninth Mid-Year Meeting, American Petroleum Institute, at the Roosevelt Hotel, New Orleans, May 18, 1939.

IT is admitted generally that the actual performance of an automotive engine affords the most definite picture of the quality of a fuel for the unit in question. The standard laboratory tests are necessary for control of properties of a motor fuel, but usually the results may be considered merely as approximate indications of the characteristics. The industry long has recognized the need for a reliable and economical combination of a laboratory and performance test.

After having studied this problem for several years, it was concluded that it would not be practicable to develop any test procedure that will meet all conditions, and that it would be best to attempt to eliminate as many of the mechanical variables as possible —particularly those that are not tied up directly with the properties of the motor fuels—and to attempt to apply a performance test that, for a controlled array of operating conditions, might be as much a test on fuels and as little a test on engines as possible. Due to the enormous number of mechanical variables in design and in actual use of engines by the public, there may be a fallacy in attempts to develop a standard actual road-performance test on both engines and fuels—although excellent work has been carried out and valuable information developed for some years by investigators along this line. Reported results of road tests are particularly illuminating as showing a great range in fuel requirements, particularly as to non-knocking characteristics—not only for various engines of a given make and model, but also for those of different design, age, and mechanical condition or adjustment. About as much success should be expected from attempts to standardize the performance of all engines in the world as from efforts to standardize the thoughts and performance of all individuals. Fundamentally, the matter appears to resolve itself into three main problems:

1. Design of engine that will give satisfactory average performance.
2. Maintenance of equipment in proper mechanical condition for best operation.
3. Provision of fuel at reasonable cost that will perform satisfactorily in engines meeting the above-noted conditions.

Accurate road tests are tedious, and a number are needed to afford reliable average values for a given motor fuel. Such tests are too expensive to serve for routine control purposes in the manufacture of motor fuels, and the results generally are employed today as a guide in fixing the equivalent limits or values for the operation of less expensive standardized laboratory tests with regular single-cylinder engines. From observation of road tests and study of reports, it was concluded that the main difficulty in development of a laboratory method that would serve the purpose of road tests lies in the time element for loading the engine and picking up speed; that it should be feasible to operate with inertia load, as afforded by a flywheel of suitable weight and design, either with or without a complementary brake or dynamometer load. Therefore, we designed and constructed a test unit along this line, and improved it as the operators gained experience in this specialized field. The rather consistent results from nearly two years of operation

have led us to place some reliance on the ratings by this method, as an indication of expected average road performance.

If one arranges an outfit with the usual power absorber in the way of an electric or water dynamometer, or friction brake, and attempts to test a fuel for knocking by operation of a regular multi-cylinder engine at normal load, with throttle open at probable maximum knock, the engine merely will accelerate in a very short time to high speed under load, so that the operator has insufficient time to observe performance at the desired range of speeds; whereas the absorption of power by the inertia-load system, with the use of a flywheel of appropriate weight, with shaft on roller bearings, affords us a time interval of about 90 seconds for observations, somewhat of an amplification of the conditions encountered by a car operator in casually throwing the throttle wide open after starting from a traffic light.

We have named our test the AIL test (acceleration-inertia-load) although this designation could be considered as referring to what "ails" the fuel. We have in this outfit a 2550-pound alloy-steel flywheel having inertia of the order of that of an automobile of average weight upon acceleration, in combination with a brake for deceleration in preparation for a succeeding test, with the necessary operating instruments and auxiliaries. The set-up is arranged so that one make of engine can be replaced by another with minimum effort—although a more extensive system would consist of one outfit for each engine to be employed, so that two or three operators could progress from one to the next, and thus be able to carry out a much larger number of determinations in a working day.

The assembly with one of the three engines regularly employed is illustrated in Figures 1 and 2, the latter also showing the overhead thermostatically-controlled water-cooling system employed. Design details are shown in Figure 3.

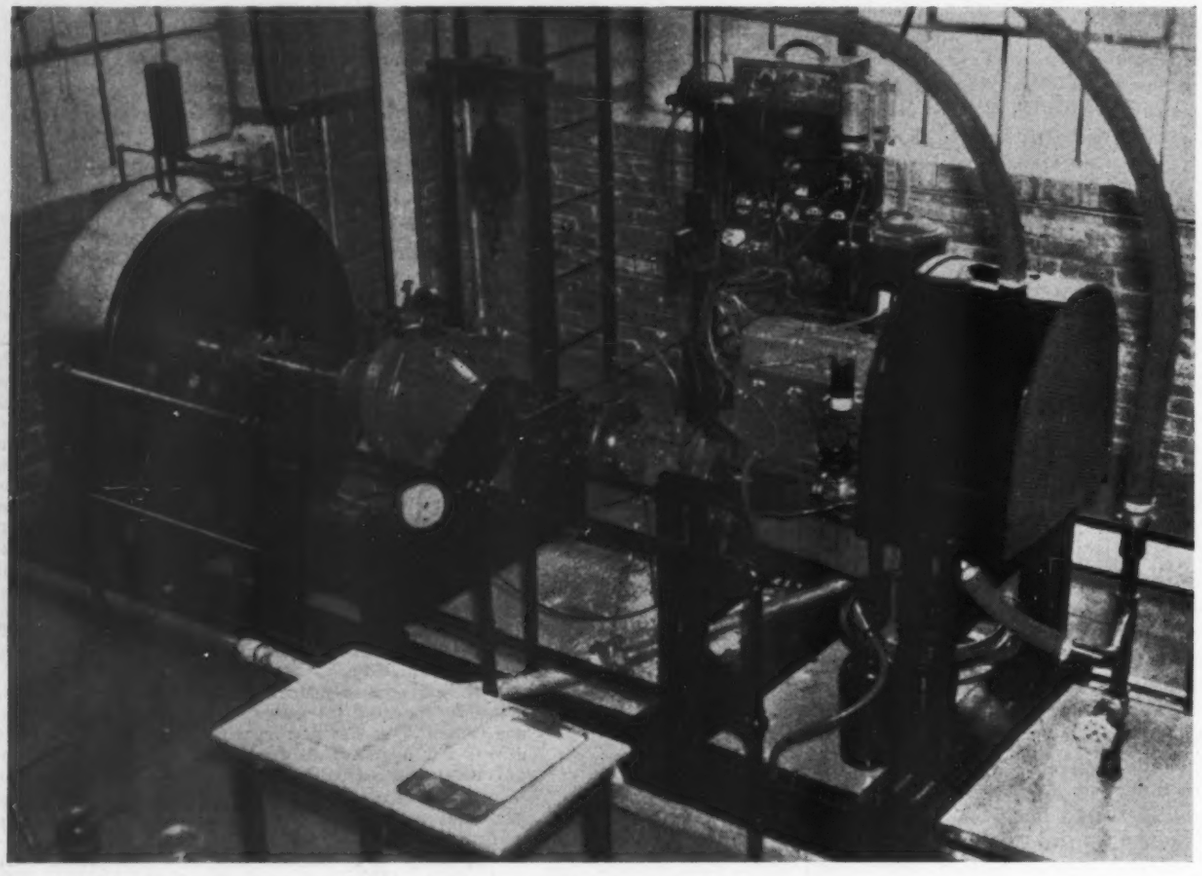

FIGURE 1
Side View of AIL Test Unit

The details of operation are outlined best by copy of our Method No. 276, offered in our regular method form, as follows:

AIL MOTOR-FUEL TEST

Scope: Determination of the detonating properties of regular-grade gasoline in full-scale automobile engines.

Apparatus: One standard Ford V-8, 85-horsepower unit; one standard Chevrolet unit; one standard Plymouth unit; the following accessories for each unit:

Clutch, heavy-duty if available; standard passenger-car transmission; speedometer and speedometer-drive gears for the standard 5-passenger sedan model; standard carburetor, except that a drain cock is fitted to the bowl to simplfy changing from one fuel to another; standard manifold heat control; standard ignition system;

One 240-horsepower hydraulic dynamometer; one special flywheel capable of being run at 3000 r.p.m., having a moment of inertia such that a torque of

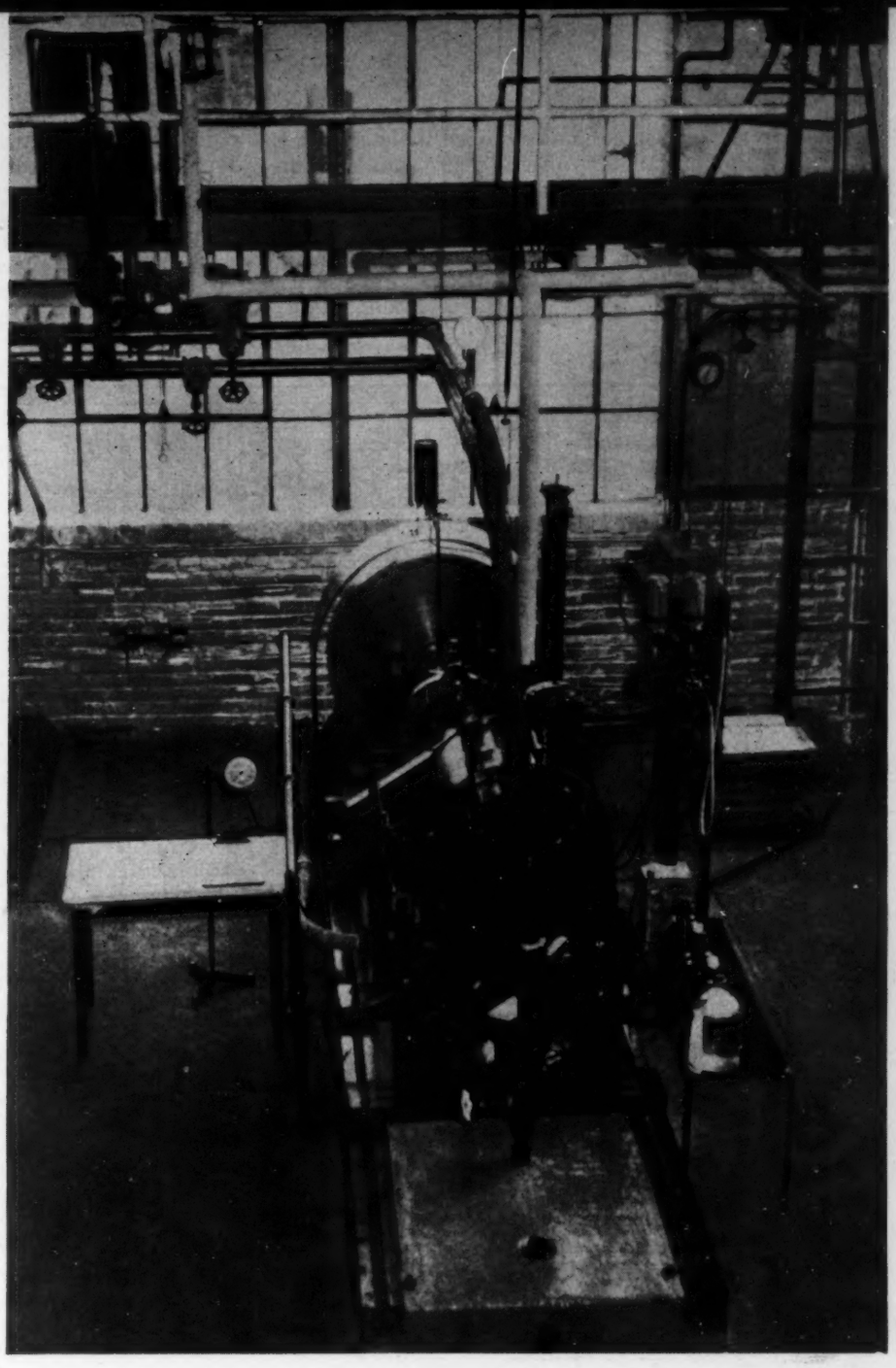

FIGURE 2
View of AIL Test Unit Showing Elevated Cooling System

approximately 135 foot-pounds is required to give it an acceleration of 0.23 revolution per second per second. (A wheel in the form of a solid, right cylinder approximately 38 inches in diameter, 8 inches thick, and weighing approximately 2550 pounds, made of forged alloy steel having a tensile strength of more than 100,000 pounds per square inch, is satisfactory when properly mounted.) One tachometer and speedometer drive consisting of an auxiliary shaft driven by a V-belt from the dynamometer shaft, a flexible cable drive being taken from each end of the auxiliary shaft; one chronotachometer to measure revolutions per minute, total revolutions, and time; one air-fuel ratio analyzer; one syncroscope for ignition timing; one manifold vacuum gauge; one oil pressure gauge; five 32 to 212°F. dial-type gas-filled thermometers, two for measuring cooling-water temperature and one each for crankcase-oil temperature, dynamometer water-outlet temperature, and flywheel-bearing oil temperature; one hygrometer with wet- and dry-bulb mercury thermometers to give room temperature and humidity; fuel-supply system to supply fuel for preliminary or warm-up runs, consisting of 2 underground tanks connected through 3-way valves to two 1-quart test-fuel containers which in turn are connected to the engine fuel pump; one engine-cooling system, connected to the engine through 2½-inch hose and pipe, consisting of a 120-gallon-per-minute 20-foot-head circulating pump drawing from a 50-gallon closed-coil cooling tank, the temperature of the cooling water through the coil being regulated by an adjustable thermostat to 180°F. (±5 degrees); one 6-volt storage battery for ignition; one special test stand to accommodate the engine-transmission dynamometer-flywheel assembly and to afford means for mounting the instrument panel and controls.

Reagents: Three secondary reference fuels covering an octane-number range from 40 to 90; standard unleaded, uncracked aviation gasoline of 70.5 to 71.5 octane number.

Note: Each reference fuel should be of a type that does not change in performance characteristics within a reasonable time in storage, and of a volatility requiring no change in the induction system from the conventional adjustments for ordinary motor fuels. To permit comparison of data with other laboratories, it is preferable to use secondary reference fuels A, C, and F, available through the Standard Oil Development Company.

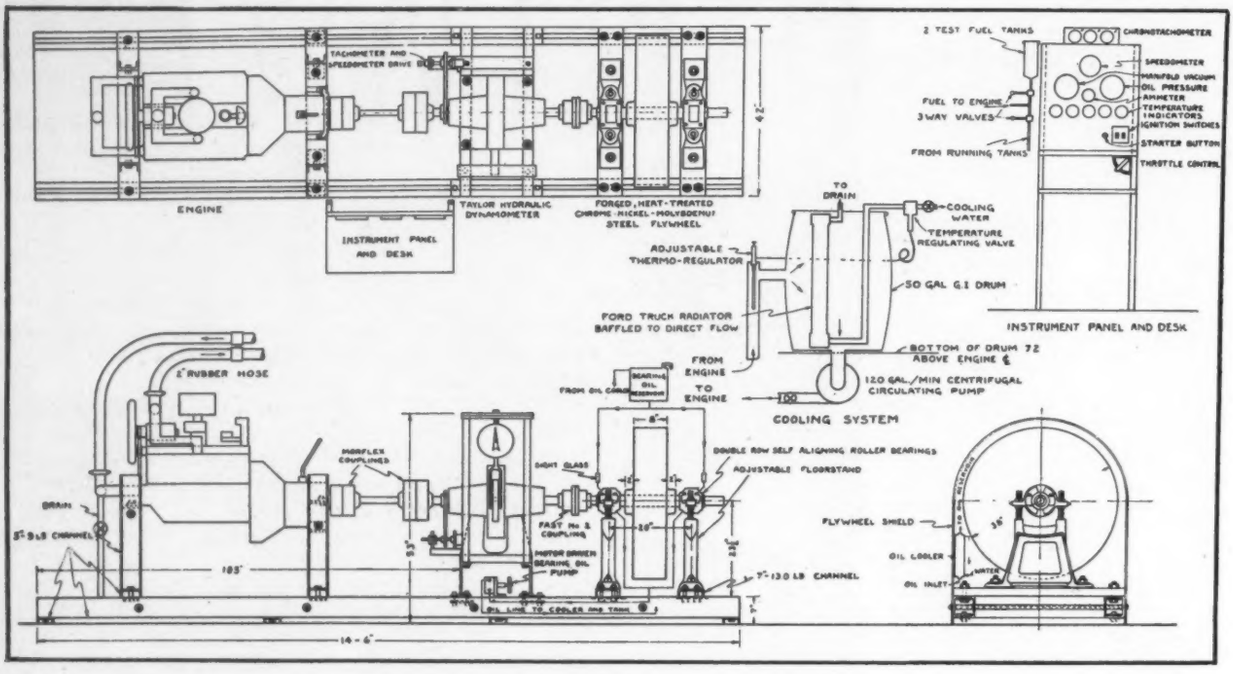

FIGURE 3
Details of Design of AIL Test Unit

PROCEDURE

Test Conditions:

Engine: The engine to be used in the test, if new, or if the carbon has been removed from it, must have been run the equivalent of at least 2000 miles at 45 miles per hour with a 25-horsepower load (these conditions being considered approximately equal in effect to 3000 miles of average use in a passenger car) prior to the test, and then checked completely and adjusted according to the manufacturer's specifications or recommendations.

Crankcase oil: A high-quality oil sufficient to fill the crankcase to the level indicated and of the grade recommended by the car manufacturer for the operating temperatures of the test.

Coolant temperature: 180°F. (±5 degrees).

Operation:

Note: For the purpose of establishing a working basis of comparison, always test the standard aviation gasoline at the beginning of a series of tests. All samples being tested, as well as all reference fuels, must be at room temperature.

Assemble the apparatus on the special test stand, connecting the transmission of the engine, through a double 10-inch Morflex coupling, to the hydraulic dynamometer, and connecting the dynamometer through a No. 2 fast coupling to the special flywheel.

Run the engine, using regular motor gasoline as the fuel, until the coolant and oil have reached the desired operating temperature; then carry out the complete test cycle several times to be sure that all parts are functioning properly.

Note: With some engines it is necessary to use an air blast over the engine, simulating the air stream of a moving car, to maintain proper oil temperatures.

Drain the water from the dynamometer, so that the entire loading of the engine is effected by the inertia of the flywheel.

Switch the engine fuel supply to the fuel tank containing the sample to be tested.

Flush the engine fuel system so that none of the previously-run fuel remains.

When the flywheel and engine have slowed down to the equivalent of 8 miles per hour, with the transmission in high gear, open the throttle to the point yielding maximum knock intensity over the major portion of the speed range employed. (This throttle opening varies with different carburetors and for different engines and, therefore, must be determined experimentally, using a fuel in the octane-number range of the unknown sample. In most cases wide-open throttle will give the best results over the entire speed range.)

In case the knock intensity of the fuel being tested is too low to give reliable readings, the ignition timing may be set ahead to increase detonation. Ignition timing must not be changed during a series of tests on any one engine, but should be adjusted to give the proper knock intensity for those grades of fuel being compared before actual tests are started.

Take knock-intensity observations as the speed of the engine increases, beginning at 10 miles per hour

and continuing at intervals of either 2.5 miles per hour or 5 miles per hour, as desired, until the maximum speed—usually 35 miles per hour—is reached. "Miles per hour" in this case refers to the equivalent car speed for a given engine.

Note: Rate the knock intensities as "none," "trace," "light," "light medium," "medium," "heavy medium," "heavy," or "destructive." Two men will be required to make the test accurately: one, the operator, to watch the speed and attend to the fuel; and the other, the observer, to make the knock-intensity observations.

Note: The identity of the fuels being run should be unknown to the observer. Each test cycle should be given a code number to be used by both the operator and the observer. The operator will keep a record of the identity of the fuel corresponding to each code number, and the observer will make comparisons of knock rating by code number only.

When the maximum desired speed has been reached, close the throttle and fuel-supply valve, and drain the carburetor bowl.

Turn water into the dynamometer, thus loading the flywheel, and slow down the engine to 8 miles per hour.

Turn the supply valve to the fuel bowl containing a secondary reference fuel, or a blend of two such fuels—which, it is estimated, will approximate the detonating properties of the fuel being tested—and flush a small amount through the carburetor, before closing the drain cock.

Turn off the water, drain the dynamometer; then, if the temperatures of the coolant and oil are normal, open the throttle to the same position as was used with the sample being tested, and repeat the procedure of accelerating to 35 miles per hour (or to the maximum speed used in the case of the sample being tested)—taking knock-intensity readings as before.

Repeat the above tests, using other blends of reference fuels, until two reference-fuel blends are found differing from each other by not more than three octane numbers—perferably two—one of which has an average knock intensity less than that of the sample, and the other an average knock intensity greater than that of the sample. The test sample must be bracketed with a run on reference fuel, a run on the unknown, and then a run on the other reference fuel.

From the CFR-ASTM calibration curve for the blend of reference fuels which matches the knock intensity of the sample, determine the octane number of the sample.

Notes: The most convenient method for arriving at the actual octane number of the sample is to assign numerical values to each degree of knock intensity, and take the sum of these numbers for each fuel to represent the average knock intensity. The AIL road rating usually reported is the average of ratings on the three different types of engines representing the three makes of cars having the highest domestic sales.

As regards operating data, there is given hereinafter a brief tabulation (Table 1) of some of the comparative figures that have been secured when applying this outfit to fuels studied cooperatively. It is interesting to note that the results from a series of tests tend to agree rather closely with the average values from a large number of road tests. In no case have we ever encountered such wide swings in values as have been reported for some road tests, although one would not expect such wide differences for an outfit which we have attempted to standardize as regards mechanical condition and operating details and for which, as noted in the above outline of the method, we first check each engine for performance value against a reserve supply of a standard fuel.

The results from 246 samples tested by complete series on all three engines indicate reproducibility of results in our own laboratories of ± 1 octane number, or less; or apparently about the same limit of error generally conceded for the ASTM-CFR method. For other results on single engines, no wider variation usually is encountered.

Some details not shown in Figure 3 have been found to improve the performance. Although the flywheel carefully was balanced dynamically by a large turbine manufacturer, it was found that a very solid support is needed for the bearings carrying the heavy flywheel in order to minimize vibration that may occur—particularly in certain speed zones; therefore, auxiliary supports consisting of 6-inch channel irons, bent in the form of an inverted "U," bolted to the base irons and to the large bolts holding the bearing boxes, were added—with marked improvement. As an additional means for reducing vibration, we filled with concrete mixture the space between the two pairs of side channel irons in the base of the unit, so as to provide a solid bedplate. Further improvement probably could be effected by surrounding the bearing supports by concrete blocks. For a new outfit we

TABLE 1

Summary of Results as Octane-Number Equivalents by Four Test Groups

Series No.	**1**		**2**		**3**	
Number of samples for series	**28**		**8**		**9**	
Testing group	**I***	**II**	**I***	**III**	**I***	**IV**
Method:						
L-3	73.0	72.9	72.5	71.8	...	...
CFR-ASTM	71.4	71.4	70.6	71.4	70.9	71.3
AIL or road car	AIL	Road	AIL	Road	AIL	Road
"A" make of engine	71.9	70.6	70.6	69.5	71.5	72.0
"B" make of engine	...	71.8	70.9	69.8	71.8	71.8
"C" make of engine	...	72.1	70.6	71.2	71.4	72.4
Average	71.9	71.5	70.7	70.2	71.6	72.1
AIL average, minus ASTM	+0.5	...	+0.1	...	+0.7	....
Road average, minus ASTM	...	+0.1	...	—1.2	...	+0.8
Range in deviation of road from AIL for series:						
"A" make of engine	—5.9 to +3.5		—2.1 to +1.0		—1.7 to +1.8	
"B" amke of engine	.....		—3.5 to +0.5		—1.9 to +1.6	
"C" make of engine	.....		—0.9 to +1.5		—0.9 to +2.1	
From averages of "A," "B," and "C"	.....		—1.9 to +0.7		—1.5 to +1.4	

* Gulf, Refinery Technology Division.

Notes: All fuels covered by this tabulation were different for all series. For series No. 1 the values for "range in deviation of road from AIL for series" are based on individual results for the AIL test for group I, but for group II on the respective average values from a large number of road tests on each fuel for the makes of engines indicated; thus the variations would be still greater in case the tabulation covered the full range of reported individual results for group II. For series No. 2 and 3, these deviation comparisons cover individual tests as indicated.

would use the next size larger roller-bearing assembly, and a 4-inch diameter shaft, and decrease the distance between the bearings about 4 inches, or as much as feasible, as a possible means of further reduction of vibration. The entire cost of this outfit (including the three low-priced engines) and instrumentation was approximately $3100, or approximately one and one third times the installed cost of one standard CFR unit.

We have endeavored to employ, in the carrying out of this test, instruments for recording the noise developed by the engine, with some degree of success—although so far we have not been able to secure or develop one for which some defects are not encountered, particularly for the range of volume of noise often involved. We have concluded that the listening, or ear, method and system of recording the knocking intensity by tabulation of symbols, such as now employed by the Cooperative Fuel Research Committee for road tests, is likely to be just as reliable as physical instruments, or more so, and we now are employing this method of recording in the same manner as for road tests. This method of recording sound observations appears to involve no more limit of error than is encountered for other operating details on this type of test, as the operators appear to be able to check values within less than 1 octane number for repeated tests on fuels handled as unknowns. However, it appears quite desirable to continue attempts to apply instruments for the study of knock intensities.

As the first unit was built entirely as an experimental one, both a flywheel and a water dynamometer of adequate capacity were provided, so that the loading could be distributed in any degree between the brake and inertia load. In operation it was found that the flywheel would give the most satisfactory and reproducible results, with no load applied by the water brake during acceleration. However, the water brake proves useful for safely and promptly slowing down the mechanism for a succeeding test. Economies could be effected by substitution of a smaller water brake or a friction brake, possibly with a little more delay in testing or increase in upkeep costs, and by the construction of several units at a time.

An important point about an outfit of this kind is the arrangement of the cooling system so that reasonable control of the conditions can be effected. In the case of this unit we do not employ the usual radiator, but circulate by pump the water from an elevated reservoir consisting of an ordinary steel drum—the temperature of the water being controlled thermostatically. As an economical means for cooling the system we employ a truck radiator immersed in the drum of water, through which separate cooling water is passed as required—thus reversing the usual system by having the circulating coolant outside the radiator. In order to duplicate air currents in normal road operation in the absence of regular fan assembly, we employ a blower fan under the engine pan during the operation.

The apparatus is very useful for indicating promptly, for a given run-of-plant production, what variations in numerical limits are to be applied for any given standard testing method for assuring uniformity of output as to road performance.

SUMMARY

It is realized that no particularly new principle is involved for this method, and that there is much to be studied and developed on the problem. This paper is offered for what it may suggest along this line, and with the hope that it will promote thought and discussion. The method appears to serve the purpose about as well as any more expensive and involved testing procedure so far proposed. The industry is certainly in need of some method that will tend toward closer general agreement as to motor-performance values.

Although this paper deals mostly with the method as a routine one for fixed testing conditions, it can be seen readily that it is a very flexible one that can be used for research purposes in studying the effect on fuel performance of variations of cooling-water temperatures, for example, as applying to higher temperatures of truck operation, as well as a range of other readily-applied changes in operating conditions or varieties of fuels. Thus, along these lines, it is believed that it could be made a research tool of value.

We also think that this method can be applied to a standardized single-cylinder testing engine, and are working on the development of a unit of this type—although some mechanical difficulties are involved. This system, with single-cylinder engine and high-temperature jacket conditions, also may have some further possibilities for aviation-fuel testing. This method of inertia loading could be applied also to chassis-dynamometer stands to duplicate the effects of acceleration of a car on a hill under actual road conditions—the rate of acceleration to be controlled by the size of flywheel and the gear reduction involved.

ACKNOWLEDGMENT

Acknowledgment is due to the force working on this problem, particularly to Messrs. Hyde M. Ballard, W. E. Lutz, Josiah French, and H. L. Pagett for assistance in construction, standardization, and operation of the unit.

Field Installation of Chromium Sheet Linings In Pressure Vessels

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THE field installation of chromium sheet linings in existing pressure vessels at refineries is described. Primarily, linings are installed for corrosion resistance, but the lining described also possesses a desirable heat-insulating characteristic which protects the vessel against thermal shock. It is shown that uncontrolled introduction of water into unlined vessels can introduce stresses exceeding the proportional limit of the shell metal, whereas lining of this type limits cooling rates to safe values.

Successful linings installed in the field have been used by the Standard Oil Company of California for more than 10 years. These were developed after experience with a number of other widely-used methods of protection. The fundamental soundness of chromium linings is established by the fact that practically all large pressure-vessel manufacturers now are offering some variety of this lining to the oil-refining trade.

This paper was presented at Ninth Mid-Year Meeting, American Petroleum Institute, at the Roosevelt Hotel, New Orleans, May 17, 1939.

IN the last few years there has been wide acceptance of various types of metallic lining for pressure vessels used in oil refining when corrosion is a factor. For a long time, lined vessels of one type or another have been used in the chemical industries; but, until recently, the oil industry chose either to replace vessels when corrosion had extracted its toll or to install various types of non-metallic linings which were low in cost but required frequent replacement. Recently, commercial fabricators of pressure vessels, alert to an increasing interest and demand, have offered several types of alloy lining to the oil-refining trade. As there is now considerable interest in this subject, it was thought that members of the oil industry would welcome hearing of experiences in lining existing vessels at operating plants rather than in fabricating shops.

Primarily, linings are installed for corrosion protection. A secondary benefit, protection against too rapid cooling or heating, is available in certain designs of lining. Still other types permit maintaining lower shell-metal temperatures—which is of considerable advantage in certain processes.

Development of a Corrosion-resisting Lining

Although the protection against too-rapid cooling has proved to be of considerable importance, it must be admitted that corrosion resistance alone was being sought when the development of a satisfactory chromium sheet lining first was undertaken. Due to the nature of the stock handled, corrosion rates beyond all expectations were experienced in our first cracking units. The art of pressure-vessel welding in 1925 had not advanced beyond the point where we felt justified in utilizing pressure vessels thicker than 2½-inch wall. In those days welds in vessels, even of that thickness, neither were stress-relieved nor radiographed; and riveted joints in these thicknesses were very unsatisfactory. The result was that corrosion allowance was avoided when its provision threw the wall thickness into a range beyond 2½ inch. Actually, only about ¼ inch corrosion allowance remained when all possible factors had been taken advantage of, including our own stress-relieving after erection. Investigation showed that corrosion rates as high as 0.1 inch per 1000 hours had to be provided for. Without lining, these vessels, costing $26,000 each, would be good for about 4 months' service. Protection of some sort was, therefore, imperative for continued operation.

Pressure-vessel linings, even chromium sheet linings, were not unknown in 1925. A number of refiners were operating with various types of ganister and other refractory lining. Between 1920 and 1924, in earlier types of cracking units, we had learned of the resistance of high-chromium steels to this form of corrosion, and a number of vessels actually were lined with chromium-steel sheets. However, all attempts to develop fully-successful protective linings failed due to inability at that time to obtain proper specification material commercially, to the undeveloped state of the art of electric-welding stainless alloys, and to lack of recognition of the proper method of bonding to the shell. Thus the method finally adopted and described in this paper was very similar to that known several years earlier and which had failed for want of sufficient appreciation of the factors just mentioned.

In the interim almost every conceivable form of protection that could be thought of by ourselves or learned from others was tried or considered. These included:

1. Brick linings.
2. Heat- and corrosion-resistant paints.
3. Intentionally applying resistant coke layers through special methods of operation.
4. Portland-cement gunite coatings.
5. Various refractory gunite coatings.
6. Portland-cement concrete cast in forms.
7. Chromium plating.
8. Sprayed metals.

Some of these methods were employed on a large scale, and offered a means temporarily of checking

progress of serious corrosion until the development of the lining process which later is described in detail. Over about a two-year period certain vessels were protected by chromium plating, followed by as many as three applications of different forms of gunite. Some chromium-plating jobs were excellent, and one 10-foot x 30-foot Dubbs evaporator in particular, protected in

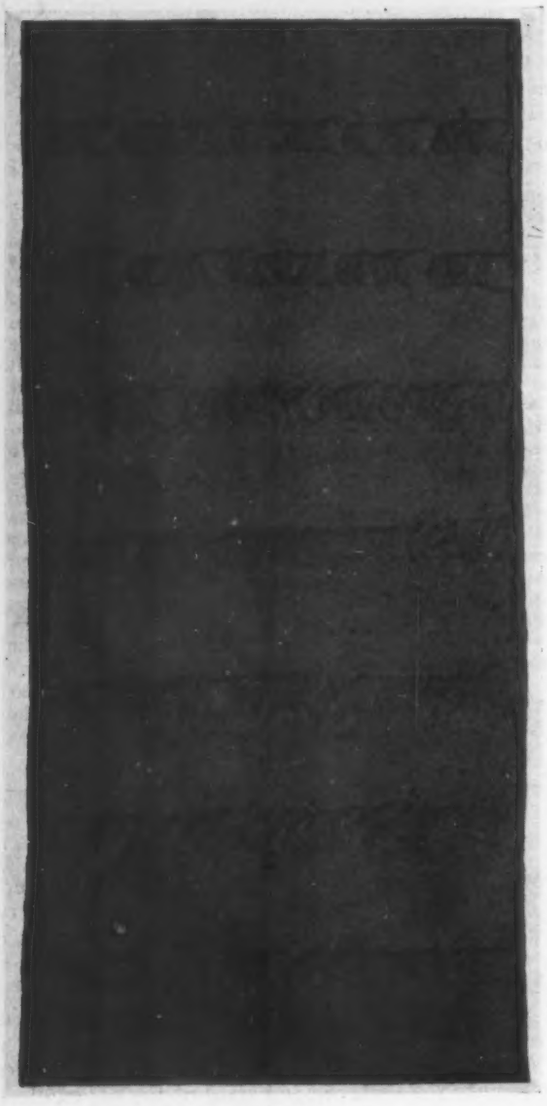


FIGURE 1
Early Strip-Type of Chromium-Steel Lining.

this manner, was in service for seven years with no repairs. However, the earlier failures discouraged further perfection of the plating methods, and the merit of the process was not recognized until after the more tangible form of protection of chromium-sheet linings had been developed. If the same continuous effort had been applied to improving chromium-plating methods as was applied later to developing chromium-sheet lining, it is possible that a practical process of protection by means of plating would have resulted.

Therefore, it was after the earlier failures of chromium plating and the annoyance of repeated renewals of gunited linings that a re-awakening of interest in chromium sheet linings occurred. Chromium plating was giving quite a substantial protection to the major portions of the areas of about 30 vessels, but was failing in spots and localized areas. As these failures became evident, the local areas were covered with small pieces of chromium-steel sheet. Some of these repairs were only a few inches square, and were successful from the start. Larger areas were covered as the early plating failed, and soon we had reached a "patch" of such size that it failed due to cracking and bulging. It was only logical to go back to the success with the small patch, only a few inches square, and wonder why an entire vessel could not be lined in this same manner with the patches or strips joining. Obviously, this was an extreme consideration; but, as continued operation was important, and as larger areas were presenting themselves for protection at each shutdown, we set out, with this plan as a limit, to learn how little welding would be required to give a satisfactory job and how it best could be distributed.

Figure 1 shows an early arrangement of this so-called "strip" lining, the separate strips in this case being about 3 inches x 10 inches. Numerous combinations of strip size and arrangement were tried, and reasonable success was obtained with 6-inch x 30-inch strips welded continuously to the shell with no intermediate plug welds. To meet the ever-increasing demand for a more satisfactory form of protection, several thousand square feet of vessel interior were lined by this method in 1928. This lining was installed in full realization that it was not the ultimate in satisfaction—but it served its immediate purpose, and provided a means of overcoming the effects of corrosion until better methods were available.

Figure 2 shows part of the interior of a 10-foot x 30-foot Dubbs evaporator lined with 6-inch x 30-inch strips. The exact identity and service history of the

FIGURE 2
Strip-Type Chromium-Steel Lining in 10-ft. x 30-ft. Dubbs Evaporator.

lining shown in Figure 2 has been lost; but no doubt it had had several thousand hours' service, as evidenced by the dense laminated layers of coke in the lower part of the illustration. Coke has been chipped off the upper portions to expose the condition of the lining. It should be noted that oil is "weeping" from porous areas in the welds. Experience showed that this in no way limited the serviceability or protection afforded in cracking service. Some smaller strips appear in the left center. These were applied long before the entire vessel had been lined in order to give protection where the earlier type of chromium plating had failed in localized areas.

Other forms of lining which were tried included arc

deposits of chromium steel. Some of these are shown in Figures 3 and 4.

Figure 3 shows a section of vessel protected with arc-deposited metal. This method was very costly, and set up high internal stresses in the shell. Its use, accordingly, was confined to small areas, to flange facing, and to protection of areas wherein inaccessibility made it difficult to apply strip or sheet lining. Figure 4 shows the etched cross-section of a plate protected with arc-

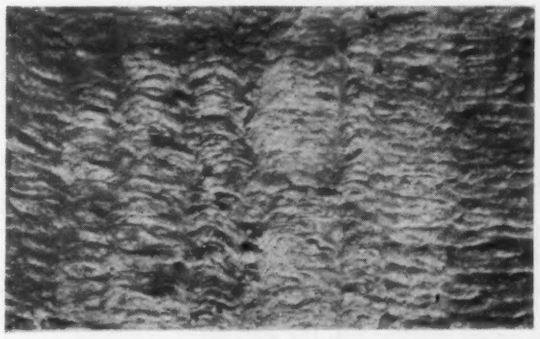


FIGURE 3
Arc-deposited Chromium-steel Lining.

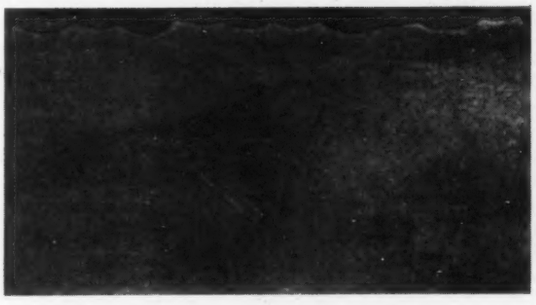


FIGURE 4
Etched Cross-section of Arc-deposited Lining.

deposited metal, and illustrates the thickness and depth of penetration. This method still is employed in certain locations on vessels.

Meanwhile our metallurgists were busy seeking better chromium sheet materials, better weld rods, and improved methods of application. These efforts finally culminated in the present practice of using special low-carbon grades of sheet, and plug-welding through 9/16-inch diameter holes on 4-inch centers, as shown in Figure 5. For several years this has been our standard practice, and most of the early strip lining has been replaced with plug-welded "panel" lining, as the former gradually failed by bulging and cracking. Even the early installations of plug-welded lining were not the most satisfactory due to failure to realize the importance of several factors later described. But, fortunately, the answer to the corrosion problem was found just when it was needed most, and plug-welded chromium sheet linings, installed in the field, now have been employed successfully by Standard Oil Company of California for more than 10 years.

INSULATING EFFECT OF LININGS

In the operation of most refinery vessels, especially cracking equipment, the cycle of operation is such that, once the unit is "off stream," every hour of shut-down time is an economic loss, and every effort is made to hasten the opening-up and cleaning of the vessels. This requires the introduction of water to cool the vessels and its contents to a temperature at which it is safe to open and to steam to the atmosphere. The consequences of rapidly cooling refinery vessels, especially heavy-walled vessels, are not recognized generally, and little has been published on the effect of different cooling rates. Many vessels have been distorted badly by rapid cooling, and many have been cracked.

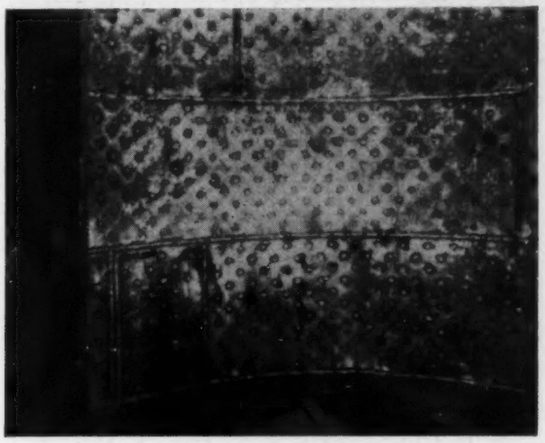


FIGURE 5
Present Form of Plug-welded Chromium Sheet Lining.

If the movement of a mild-steel member is constrained and its temperature is changed approximately 150° F., stresses exceeding the yield point of the material are introduced. At elevated temperatures this effect becomes more serious owing to the reduction of yield point and proportional limit, the decrease in elastic modulus, and the increase in coefficient of expansion.

The effect of plug-welded chromium sheet lining on heat transfer was demonstrated by making tests on both lined and unlined plates 2½ inches thick, and provided with the standard thickness of heat insulation as applied to the outside of vessels. The plates were heated in a furnace to the desired temperature, and water was flowed over the upper surface of both plates. Thermocouples were provided for determining temperatures throughout the thickness of the plate.

Upon the application of water to the unlined plate, the wet-side metal temperature dropped rapidly, as shown in Figure 6, until a differential of 300° F. existed ½ minute after the application of water. This introduces high tensile stresses in the wetted side of the plate during the first few minutes of cooling.

In the case of the lined plate, the temperature of the lining material dropped almost immediately to 212° F. However, this did not affect greatly the steel plate itself, and the temperature of both surfaces fell off slowly—the maximum temperature differential amounting to only 43° F., and occurring about 2 minutes after the application of water. On subsequent runs the maximum differential was progressively smaller due to increasing warpage of the lining caused by the sudden application of water.

The temperature differentials corresponding to stresses at the proportional limits throughout the temperature range were calculated, and the resulting wetted-surface temperatures are shown as the dotted lines in Figure 6. Referring to these curves, it will be seen that in the case of the unlined plate stresses well beyond the

proportional limit of the material exist during the first 3½ minutes in which the water is in contact with the plate. In the case of the lined plate all parts of the cooling curve are well within the temperature limits corresponding to stresses at the proportional limits throughout the full temperature range.

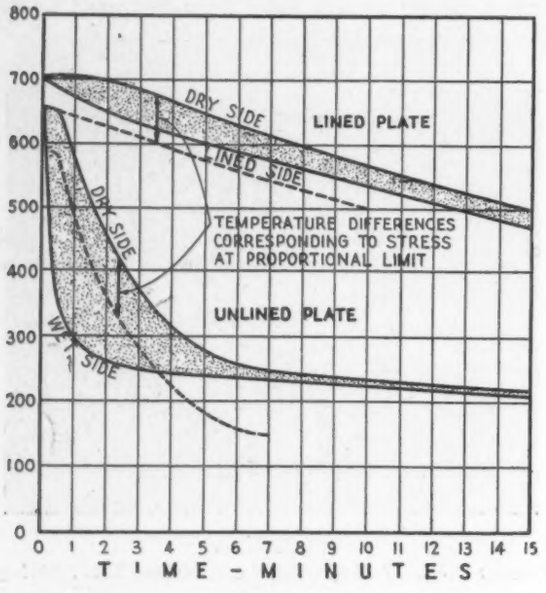


FIGURE 6
Cooling Rates of Lined and Unlined 2½-inch-Thick Plates.

Thus the type of lining herein described protects the vessel against large temperature differentials, and insures safe cooling rates. Gunite linings and linings of various insulating materials would have the same or even greater effect. Integral types of linings such as electroplated, weld-deposited, and sprayed metal linings obviously possess this characteristic to a lesser degree. It is, therefore, well to investigate the heat-transfer characteristics of the particular lining to be used, and to establish permissible cooling rates of vessels, on a basis which will limit the stresses to safe values.

Certain types of linings, having rather high insulating values, may be desirable for their insulating value alone. Through their use, shell-metal temperatures may be reduced to a value that will permit considerably higher operating stresses than are possible with the normal process temperature. This often avoids the use of special high-strength alloy material, and results in lighter-wall, more economical shell construction. It is also often possible to increase considerably the permissible working pressure of existing vessels in high-temperature service by installing internal insulation in the form of a lining.

DESCRIPTION OF FIELD INSTALLATION OF CHROMIUM SHEET LINING

Specifications for Lining Materials

Sheets: Naturally, the sheet material primarily must be selected with resistance to the corrosive media in mind. A number of compositions are employed to resist corrosion in various processes, from carbon steel at one extreme to 18-8-3 chromium-nickel-molybdenum alloy at the other. However, the most important and, therefore, the subject of the present discussion, is the 11 to 13 percent chromium grade, which has been found highly resistant to all conditions encountered in our cracking processes.

For linings in cracking service a special low-carbon grade of 11 to 13 percent chromium steel is employed. The specification for purchasing this material is as follows:

1. The metal shall conform to the following chemical composition:

	(Per Cent)
Chromium	11 to 13
Carbon	0.08 (maximum)
Nickel	0.50 (maximum)
Manganese	0.30 to 0.70 (maximum)
Silicon	1.00 (maximum)
Phosphorous	0.035 (maximum)
Sulfur	0.035 (maximum)

2. The sheets shall be hot-rolled and annealed.
3. The sheets shall be white-pickled after annealing and before final inspection.
4. The resulting hardness shall not exceed Brinell 174 (Rockwell C-7).
5. The sheets shall be free from inclusions, hard spots, seams, laminations or other flaws that would render them unfit for service.
6. The metal must be capable of being bent flat on itself without cracking on the outside of the bend.

The chromium content is a compromise between the lowest that will give satisfactory corrosion resistance and the highest that will resist embrittlement at operating temperatures.

The carbon content specified is the minimum obtainable commercially; it should be as low as possible. As this is written, it is understood that some suppliers now are offering a 0.06 percent (maximum) carbon grade. If obtainable, this should be specified. The low carbon content of the material, more than any other single item, is believed to be the key to successful installation. The lower the carbon content, the less is the tendency to form chromium carbides during the welding process. The chromium carbides are air-hardening, and result in brittle zones next to the plug and fillet welds.

The sheets must be in the fully-annealed condition for punching and for shaping the edges. They receive plenty of abuse during the installation process, and should start out in the best condition possible. This is the reason for the hardness limitation and the bend test. Material meeting these requirements, when welded with 18-8 chromium-nickel electrodes, can be bent flat on itself.

Inspection, which should be very rigid in material of this type, is facilitated greatly by pickling. Although appearance, as such, is of no importance after installation, pits, tears, and laminations are indications of poor processing and lack of skill on the part of the manufacturer. The attendant expense of installing the lining and the difficulty of replacing failed sections are too great to consider using anything but the highest-grade material. Inspection at the mill is more desirable than inspection on receipt; as marginal-grade material can be rejected with less embarrassment, delay, and cost on the part of both supplier and purchaser.

It might be of interest to mention that the addition of ½ percent molybdenum to the sheet material is being tried out. It is anticipated that this will improve the welding quality and serviceability, but it probably will be several years before any comparison can be made, as the present straight-chromium composition has a very long life.

Weld rod: Several brands of low-carbon 18-8 chromium-nickel electrodes with carbon-free coatings have been found suitable. The prime requisite is to use a rod with which the particular welder can make sound,

smooth, low-carbon deposits in the side-hand and overhead positions while welding through the punched hole in the lining. Selection of the brand of rod should be made only after actual trials under these conditions. Rods which give lumpy uneven deposits, resembling popcorn in appearance, are to be avoided. The rod size will vary with lining thickness, position of welding, and personal preferences and capabilities of the welder; but 1/8-inch and 5/32-inch rods generally are preferred.

Qualifications of Welders

In selecting welders for field installation of chromium sheet lining, it should be remembered that an expensive, critical job is being installed. Not only the welder's ability to make a good test weld should be considered, but also his attitude towards doing continuous, tedious work under uncomfortable conditions. In a typical fractionating-column lining job there may be as many as 15,000 plug welds and as much as 1500 feet of seal welding, mostly in the side-hand and some in the overhead position. Welding fumes, flashes from nearby welders, and the din of pneumatic hammers "laying up" the partly-welded lining all contribute to the fatigue and annoyance of the welder.

Another factor demanding the best in a welder is the tendency to hurry the job, because most field installations are made in equipment already in operation in which the cost of a day's down-time usually is calculated in four figures, or because seasonal commitments for gasoline are a consideration.

Before welding in the vessel, the welder should be required to make smooth, workmanlike welds — both plug welds and fillet-seal welds — in the side-hand and overhead positions, if he is to work in both. Appearance of the welds, as such, is of no significance except as an indication of the skill of the welder and the suitability of the electrode as well as of arc conditions. Lumpy, rough, and porous welds are an indication that something is at fault, either in the technique of the welder or in the materials and equipment with which he is working. Experience has shown that it is a costly mistake to proceed with the lining operation before the welders have been trained adequately.

Reasonable provision for the comfort and protection of the welder will add to the quality of the work. Platforms should be provided to keep the work at comfortable working height. If a number of welders are employed in the vessel, artificial ventilation may be necessary. Blowers, exhaust fans, and steam eductors all have been found satisfactory. When welders are working in close proximity to each other, good facilities for personal protection are necessary. In addition to canvas curtains arranged to protect the unguarded eyes against direct exposure to the arc, it has been found desirable to have the welders wear light-colored goggles under the welding helmet. This practice protects the eyes, when the helmet is raised, against secondary radiation and reflection off the metal surfaces, as well as against the rapidly-fluctuating intensity of the light due to neighboring arcs. Properly-outfitted welders are shown in Figure 7.

PREPARATION OF INTERIOR SURFACE OF VESSEL

Preparation of the surface to be lined is of no less importance than other factors mentioned. The surface must be well sandblasted; and, if the vessel already has been in service—which is the usual case—all traces of oil and coke must be removed. This is not easy to accomplish in a riveted vessel or in one which is badly pitted. In the former, oil often seeps from the joints for a long time after cleaning. If a clean surface canot be obtained in any other way, it may be necessary to caulk or seal-weld the joints and rivets. If the surface is badly pitted, it may be necessary to mark off the location of the plug welds and build up the surface locally with carbon steel to permit properly attaching the sheets to the vessel. Pits and voids up to a few square inches in area do not affect the serviceability of the lining, provided they do not fall in the way of the plug welds. Naturally any extensive corrosion which has occurred prior to installation of the lining should be given consideration from the standpoint of its effect on the safe operating pressure of the vessel.

FIGURE 7

Protection for Welders.

Each welder is protected from direct arc flashes of his neighbor by means of canvas curtains. To guard against indirect reflections when the helmets are raised, each welder wears light-colored goggles under his helmet. With good ventilation, these arrangements permit working a number of welders in close proximity, and speed up the job.

Sandblasting dust must be blown or swept from the surface and from pits and cavities.

PREPARATION OF SHEET FOR INSTALLATION

Dimensions of the individual sheets are chosen arbitrarily, of course, but for economy they should be as large as can be passed through the manway and handled readily. For instance, if the vessel to be lined is equipped with 24-inch manways, sheets 23 inches x 120 inches will be found to be most suitable. For vessels of small diameter, shorter sheets will be required.

Considerable latitude is available in the selection of gage of sheets. Corrosion is, to a certain extent, a factor in choosing thickness; but our experience has been that the thinnest linings used, 15-gage, do not fail due to corrosion. A conservative course was established in the first installations, and a good deal of 11-gage material was used; later 13-gage was used, and now the usual practice is to install 15-gage. For lining small nozzles, in which it is difficult or impracticable to apply plug welds on adequate center distances and on installations where the lining is subjected to abuse from mechanical coke cleaners, 13-gage material still is used.

Holes 9/16-inch in diameter are punched on 4-inch diagonal centers over the entire area of the sheet. When manways, nozzles, or other connections or appurtenances are encountered, the sheets are shaped to conform either by shearing or by cutting with an electric arc, using a mild-steel heavy-coated electrode.

The sheets are offset on two adjacent edges to provide a lap of about 1 inch, and are rolled to conform to the

shell curvature. It has been the practice to lay the sheets with the longest dimension circumferentially.

It has been our practice to inspect pressure-vessel welds periodically for evidence of surface cracks and defects. To facilitate this inspection, the vessel welds are not covered with the shell lining, but instead are covered with a "batten" strip after a filler strip has been

FIGURE 8
Sheet Lining Tacked in Place Ready for Plug Welding.

Notice the pre-formed sections fitted over the tray support; also the method of overlapping the lower sheet.

tacked in place. This is purely an inspection expedient, and may be employed or not, as the owner sees fit; however, it adds somewhat to the expense of lining, and must be provided for in laying out the sheet arrangement. Details of this "batten" strip are shown elsewhere.

Installation of Lining

Lower costs of installation and better service from linings result when installation can be made with the vessel on the ground—where it can be rolled to permit down-hand welding, and where scaffolding can be dispensed with. However, this is not generally possible, and the lining must be done with the vessel standing vertically—employing side-hand welding on the shell, overhead welding on the top head, and down-hand welding on the bottom head.

In the usual case of the vessel standing vertically, it is preferable to start at the top of the shell; and, after having completed one ring of lining, to work down. This permits easy arrangement of the lap joint at the bottom of the sheet, so that the seal weld can be made down-hand. If conditions require starting at the bottom and working up, a little more difficulty will be experienced in forcing the lower edge of the second course under the offset on the top of the first course.

The sheet is placed in position, with the offset edge at the top, and is forced against the shell with a jack or air dolly at its center. It then is tacked to the shell through one of the center holes by running a bead across the bottom of the hole. The dolly is moved about the sheet, forcing it against the shell; and tack welds are made every third hole—moving progressively outward from the center. This procedure eliminates accumulation of slack. The non-offset edges of the sheet are tack-welded to the shell in 1 inch to every 6 inches. (Refer to Figure 8.)

After tack welding of a sheet has been completed, the entire area is gone over with a light pneumatic hammer to insure a tight fit to the shell. Care should be used in this operation in order not to scar the sheets badly or overwork and embrittle the material. In placing subsequent sheets, the overlapped portion is hammered in this same manner to secure a snug-fitting joint before welding.

The plug or button welds are deposited with a weaving bead. In the side-hand position, welding is started at the bottom of the hole, working upward. Welds are made in a single pass, avoiding building up beyond the surface of the sheet; as projecting welds cause coke accumulations, and increase the difficulty of cleaning the vessel. Every effort should be made by the welder to obtain good penetration of the weld deposit into the shell of the vessel, and to avoid slag pockets at the edges of the weld. The button welding of each sheet is completed before making the joint welds. The latter are made using a continuous full-fillet bead.

When the welding has been completed, the sheet is forced against the shell with a pneumatic hammer to eliminate drawing and distortion due to welding. When the lining is not properly "laid up" against the shell, the condition can be detected with a light machinist's hammer. Lining which adheres tightly to the shell sounds and feels solid when struck.

The slag should be removed from all button and joint welds by sandblasting. An inspection should be made for porosity and cracks. In cracking-plant service it

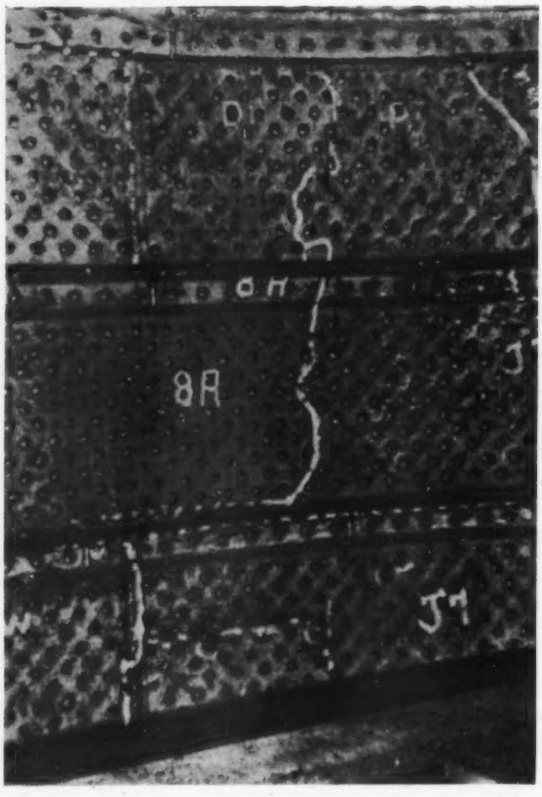


FIGURE 9
Completed Lining.

The white lines enclose areas welded by various welders, whose numbers are shown. Each welder is required to identify his work, and is held responsible for its quality.

is not essential that the welds be free from all pinholes and the lining "bottle" tight, as coking action usually seals minor openings. However, these defects are usually indications of poor welding or underlying defects, and it is good practice to chip out and repair any evidence of unsoundness. Linings installed in this manner have to contend with severe operating condi-

tions, and should not suffer the additional handicap of poor workmanship.

In applying subsequent courses of sheets, vertical joints should be staggered. (Refer to Figure 9.)

Lining Heads

Lining is applied to heads following the same principles as in lining the shell. The head is laid out in segments, the number of such depending on the degree of curvature encountered. Some trials may have to be made to determine the best size of segment. Until some experience has been gained, it is well to keep the segments small, and to sacrifice lower installation cost to gain a well-fitted job. The location giving the most trouble will be the knuckle radius of the head. When installing head linings for the first time, it would be well to cut, fit, and weld one segment only before cutting up the remaining material. This will permit altering the size of the remaining segments if any difficulty is experienced.

The segments should extend from the manway lining to the shell lining in a single piece if possible. If the head contains no manway, a disc 18 inches to 24 inches in diameter should be installed in the center—being punched, plug-welded, and seal-welded at the edge as in the case of shell lining. The narrow edges of the segments then can be "landed" on this disc, thus avoiding running all the segments to a point. Allowance should be made for a 1-inch lap, and the wide edge of the segment should be inserted under the offset upper edge of the shell-lining sheet unless a weld-inspection batten strip is to be installed. Tacking, hammering, and welding should proceed as in the case of the shell lining—particular care being taken to obtain a close fit with the head in the vicinity of the knuckle.

Nozzles, Manways, Riveted Joints, and Internal Members

Construction details such as those listed constitute the troublesome part of the job, and the natural tendency is to neglect them. Detailed supervision must be maintained in order to obtain the most careful fitting-up and welding.

Whenever possible, the lining in nozzles and manways should be plug-welded in the same manner as shell lining. If nozzles are too small in diameter (or too long) to permit obtaining good plug welds, it is essential that 13-gage, or even 11-gage, sheet be used. The nozzle and manway linings should not be ended at the shell lining and corner-welded to it, but should be extended inside the shell about 1½ inches and flared out against the shell. A substantial fillet weld then is run around the outer edge of the flange, forming a diaphragm-like connection which allows slight longitudinal movement of the liner.

The complexities of fitting the lining around some internal obstructions and irregularities may require leaving small void spaces behind the lining. In all cases these should be filled with a mixture of heavy tar and coke, mixed to a heavy jelly-like plasticity. This mixture should be pumped, with a grease gun, into the bottom of the void space. The space should be vented at the high point, and injection of the mixture should continue until it is certain that the voids are filled. Sufficient injection holes and vents should be installed to insure this condition has been accomplished. Small discs are welded over the holes when filling is complete. The mixture bakes out to a dry coke under operating temperatures, and prevents large accumulations of oil and gas getting behind the lining in the event leaks occur.

The flange faces of nozzles and manways are protected by weld deposits of stainless steel. These deposits are applied with 18-8 chromium-nickel rod in order that the flanges may be faced with a portable flange-facing tool without need for annealing. Deposits are carried out beyond the gasket face. The lining is fillet-welded to the deposit on the flange face to form a continuous alloy-steel protection.

Manway heads or cover plates are lined by applying a disc in the same manner as the shell lining, almost out to the gasket face. The area from the edge of this disc to beyond the gasket face is protected with an alloy weld deposit, machined to form the gasket surface. The use of 18-8 rod will obviate the need for annealing prior to machining; but if annealing is feasible, a deposit made with an 18 percent chromium rod will result in satisfactory protection at a lower cost.

Riveted vessels are protected by bringing the shell lining up to each side of the joint just short of the rivets. The edge of the lining next to the caulked edge is flanged over a distance somewhat more than the thickness of the shell plate. An offset strip is made to cover the rivets. This is landed on the flanged edge of the lower sheet, to which it is fillet-welded, and it then is welded to the upper sheet of lining. This strip should fit close to the tops of the rivet heads and the space between it, and the shell should be filled with the mixture described previously. Longitudinal joints are protected in the same manner.

Internal members such as braces, tray supports, beams, internal piping, etc., must be protected in the same general manner as described previously. These require individual consideration, and it would be almost impossible to describe in detail how each of the numerous cases should be handled. Sketches are included showing typical methods of handling the lining of such details. (Refer to Figures 10, 11, 12, and 13.)

FIGURE 10
Pre-formed Sheet Lining for Installation Over Tray-Support Angle.
Figures 11, 12 and 13 show these sections in various stages of being welded into place.

COSTS

As might be expected, field installation of chromium sheet lining is an expensive job. Practically all linings were installed after the vessels had been placed in service; and many were lined, one 23-inch course at a time, between cleaning shutdowns, in order not to interfere with badly-needed cracking-plant capacity. The cost also varies widely with the number of nozzles and openings, and with the complexity of internal members which must be protected.

It is probable that lining costs will run between $5.00 and $10.00 per square foot, depending on the influence of the factors mentioned previously. The economy of lining as compared with replacement involves not only cost of lining, but consideration of numerous factors

such as freight, erection cost, and time to deliver replacements; and each case must be studied individually.

Serviceability

Serviceability of linings is about as variable as their costs, due largely to the inability to say just when a lining has failed. After relatively few runs, chromium sheet lining becomes buckled between plug welds, and looks somewhat like a quilt. If a new user had purchased such a lining from a commercial fabricator, he would be inclined to want his money back; for the lining certainly does not look much like it did when installed. However, experience has shown that this appearance does not affect the serviceability of the lining; and, after the first buckling between plug welds, little additional change may take place for several years.

FIGURE 11

Tacking of Pre-formed Sheets Around Tray-Support Angle.

Occasionally local areas involving several adjacent plug welds will pull away from the shell and form a large "blister." If the plug welds pull off the shell rather than out of the lining, it is probable that protection in cracking service is not reduced. However, it is our practice to cut out this area of lining with an arc using a mild-steel electrode, and to install a new patch of lining. Such occurrences are rather rare, however, when good welders have been employed.

An over-all figure on maintenance of linings is hard to determine; but a fair estimate, based on observing about 50,000 square feet of lining over an average period of 6 to 8 years, would be the replacement of 1 to 2 percent per year.

A specific example of lining experience over an extended period is the case of four 8-foot x 60-foot 2½-inch wall combination reaction chambers and fractionating columns lined in 1930. These vessels have no provision for corrosion allowance, and would have had to be made about 3¼ inch thick to last one year if unprotected. The lining has been inspected periodically since installation, and has been observed to be failing progressively; but only a negligible amount of maintenance work has been done. At a recent inspection these linings were scheduled for replacement this summer, having given 9 years' protection.

The great bulk of sheet-lining installations was made between 1928 and 1931, and still is operating, with only minor maintenance. Numerous improvements in materials, design, and technique of installation have been made since, and linings installed in the last few years can be expected to give somewhat better service and endure more drastic cooling conditions than the early linings. In 1935 four 10-foot x 30-foot 2½-inch wall vessels welded in 1926 were returned to the manufacturer, and were re-welded into two 10-foot x 55-foot vessels to accommodate certain process changes. Advantage was taken to renew all welded seams with modern stress-relieved and radiographed welds. The old lining, installed in numerous small increments in 1928 and 1929, was left in place while the vessels were cut up, re-welded, and stress-relieved. After the vessels had been returned to the refinery, the worst of the damaged lining was patched up, and new lining was installed over the welded seams. Today, this lining is still in service, and maintenance is negligible—probably less than 1 percent per year.

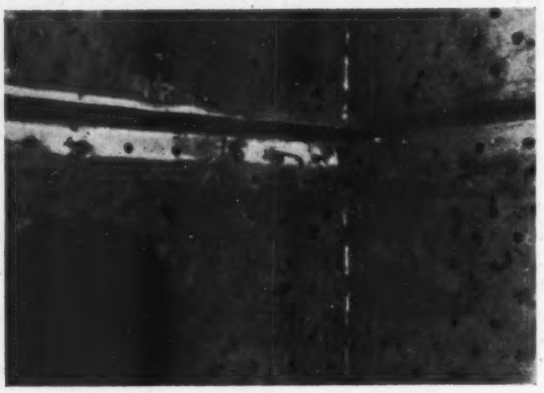


FIGURE 12

Lining Fitted Around Tray-Support Angle and Intersection of Shell with Baffle.

None of the lining has yet been plug-welded, and the sections fitted about the tray support on the baffle have yet to be hammered snugly into place.

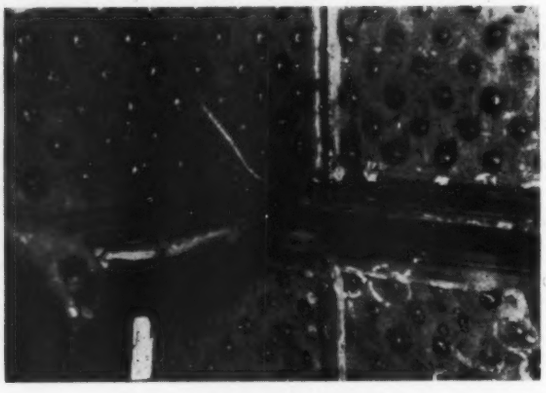


FIGURE 13

An Area Similar to That Shown in Figure 12 After Final Welding.

In 1937 two 8-foot x 50-foot 1-13/16-inch wall carbon-molybdenum vessels were lined at the refinery

upon receipt from the fabricator. Sufficient time was available to line these vessels while they were on the ground, and all welding was done in the downhand position. These vessels are in perfect condition today, absolutely no repair work having been done to the lining except in the case of the weld-protecting strips which were made 8 inches wide without intermediate plug welding.

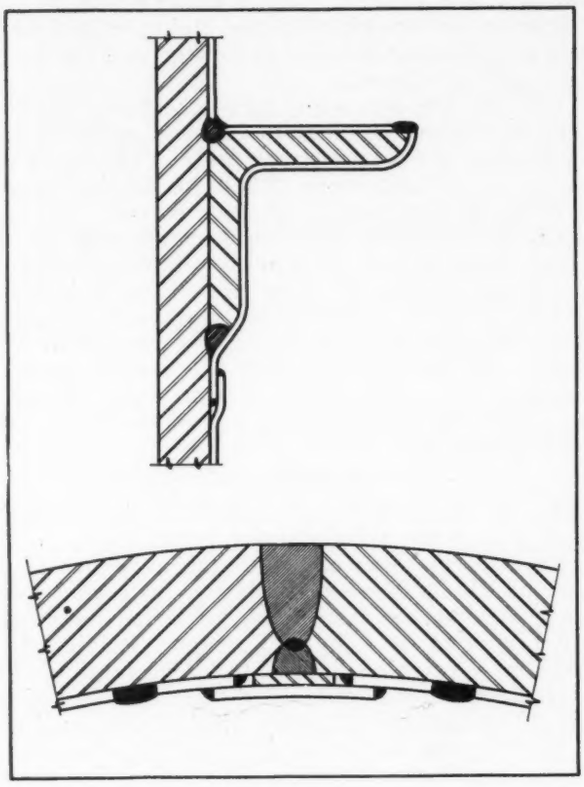


FIGURE 14
Typical Details of Chromium Sheet Lining.

It is difficult to give any single figure or any group of figures, readily interpretable, that would provide an index of performance or unit cost of maintenance of sheet linings. Since 1928 linings have been installed in all conceivable manners, some good and some bad; and yet much of the original sheet is still in service. That much of this lining is now very old is illustrated by the fact that an old record shows that more than 32,000 square feet of lining was in service by the middle of 1931. A single figure for maintenance would be about as meaningless as would be a single figure representing the average cost of automobile maintenance including all models since 1900. The best index of performance is the acceptance which operating management has given this type of lining.

The use of field-installed linings has been extended to other processes than cracking, and to other equipment than vessels. For a number of years large steel castings in corrosive hot-oil service, such as hot-oil circulating-pump cases, have been lined in this manner; 18-8 chromium-nickel linings have been installed in phenol-extract recovery towers at our solvent-refining plant. At the present writing an 18-8-3 chromium - nickel - molybdenum lining is being installed in a 19½-foot diameter 90-foot high vacuum distillation tower in crude-distillation service.

This last installation represents an interesting case of lining economics. Corrosion rates are not particularly high, and in the case of a new vessel easily and most economically could be taken care of by adding to the shell thickness. However, practically no corrosion allowance was provided for originally, and no further losses can be permitted. The vessel is so large that it had to be constructed by welding in the location and position in which it was to operate. Therefore, the vessel—together with its insulation, connections, internal structure, etc.—represents such an investment that lining with this expensive alloy material readily can be justified. No alloy between the extremes of carbon steel and the 18-8-3 alloy gave substantial resistance to the corrosive media. Although additional steel in the original shell would have proved economical, a sufficient thickness of carbon steel could not be installed as a lining because of lack of available space between the corroded shell and the existing tray structure.

CONCLUSION

In closing, it seems in order to mention briefly some of the commercial lining processes. These are being advertised in trade journals, and it is probable papers will appear currently treating them from an engineering standpoint. Some of the largest fabricators in the country have developed their own linings

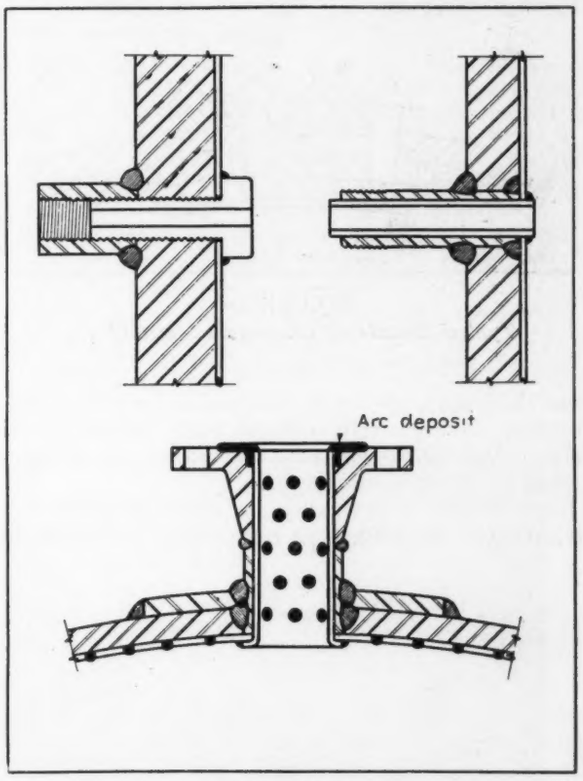


FIGURE 15
Typical Details of Chromium Sheet Lining.

to a high state of perfection. Not faced with the need for installing the lining in the completed vessel between operating runs, having access to various types of automatic welding processes, and being able to line flat plates prior to rolling, these fabricators no doubt have reduced costs below those possible in field installation. The good appearance of such linings is also an important consideration, both when newly applied and after a period of operation.

Some commercially-applied linings consist of a

sheet resistance-spot-welded on close centers, leaving a small unwelded area between spots; others consist of a sheet resistance-spot-welded in a manner that the adjacent spots overlap, giving the effect of a continuously-welded or integrally-bonded lining; others consist of an alloy deposit fused to the steel, the composite material then being rolled to final

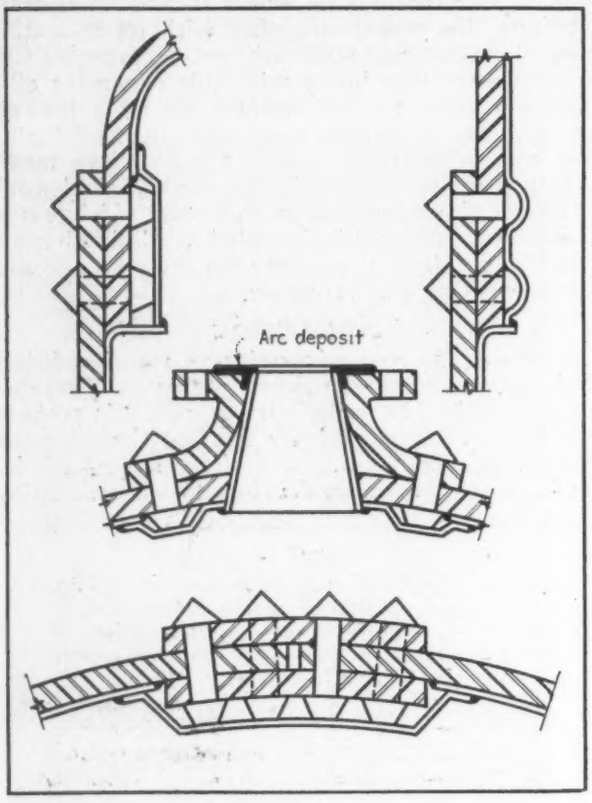


FIGURE 16
Typical Details of Chromium Sheet Lining.

plate thickness, giving a continuous integrally-bonded alloy facing; still others have installed plug-welded linings essentially the same as those described in the present paper.

Each of the above types no doubt has individual advantages, and each type may find a particular field of adaptability in which it may receive most general acceptance. The matter of relative heat transmission may be very important in some services, and of no consequence in others; the adaptability to field-installation methods may outweigh all other advantages; the matter of stress due to differential expansion best may be met in some cases by allowing a spot-welded lining to buckle between spots, and in others by absorbing the stresses proportionately in lining and in shell; slight leakage due to local separation or cracking of the lining might be of little consequence in some processes, and totally unacceptable in others.

Our company has approached the lining question from an engineering standpoint, and with an open mind. Although it takes some pride in having carried forward the development of field-installed chromium sheet lining to a fairly high state of perfection, and currently is making additional installations of this type, it has not been blind to the progress and efforts of others. Within the last two years it has purchased 20 vessels lined by pressure-vessel manufacturers. Some of these were obtained from each of the leading fabricators; and included various types of attachment to the shell, various compositions of lining material, and a wide range of vessel sizes and wall thicknesses.

ADDENDUM

Shortly after the manuscript of the foregoing paper had been submitted for publication, the author's attention was called to the existence of another article having nearly the same title and covering somewhat the same field, published under date of February 21, 1939, by K. E. Luger, Stainless Steel Division, Carnegie-Illinois Steel Corporation. This excellent presentation, entitled "Field Lining of Refinery Vessels with Stainless-Steel Sheets or Strip," includes a cross-section of the practices of numerous people in addition to the method described in the present paper.

Our first reaction was that the prior publication of Mr. Luger's paper would lessen interest in the presentation of another on a similar subject; but, upon further consideration, it was felt that the direct experiences of those actually engaged in pioneering the development of one of the specific types of lining and a fuller discussion of the economics, serviceability, and advantages would be worthwhile.

Multi-Layer Construction *of* Thick-Wall Pressure Vessels

T. McLEAN JASPER
A. O. Smith Corporation, Milwaukee, Wis.

MULTI-LAYER construction is a development which has grown out of the failure of small thick-wall high-pressure vessels to give the service expected of them.

Four such thick-wall pressure vessels, 12 feet long, with an outside diameter of 33¼ inches, and a total wall thickness of 3⅝ inches, were built in the Smith plant several years ago and tested to destruction. In no case was the pressure value at failure more than 75 percent of what had been expected according to commonly-accepted cylinder formulas. A careful study of the test data thus gathered made it apparent that the accepted formulas were not applicable for heavy solid-wall "small-diameter" vessels, i.e., vessels in which the ratio of diameter to wall thickness $\frac{D}{t}$ was in the neighborohood of 10 or less. Examination of the available literature on the subject failed to produce any record of previous destruction tests with high-pressure vessels of these dimensions—whether welded, forged, or cast.

This situation acted to spur on a thorough investigation of improved construction ideas. Multi-layer construction showed a marked superiority over all other proposed methods. A patent was secured covering this construction.

This paper was presented at Ninth Mid-Year Meeting, American Petroleum Institute, at the Roosevelt Hotel, New Orleans, May 17, 1939.

THE multi-layer vessel is constructed of several layers of de-scaled steel, each progressively wrapped and tightened around the cylinder by mechanical means and then welded together at the edges. Figure 1 shows two vessel sections in the course of construction. The discs inserted in the ends are to hold the inside layer in position while the first few subsequent layers are added. The thickness of each outside layer is generally less than ¼ inch, whereas the inside layer may be heavier. Only the inside layer is leakproof. Each subsequent layer is perforated with small holes for venting.

After all layers have been added, the ends are machined for the welding groove, as shown in Figure 2. The contact between layers is so uniform that it is difficult to determine from visual inspection that the vessel is not made from solid steel plates (see the close-up view, Figure 3).

With the ends machined, the sections are assembled by welding in a manner similar to the way sections of solid-wall vessels are joined.

There are, of course, many other details of construction. Some of these are brought out in the following resume of Smith's experimental history with this construction.

In 1931 two vessels of multi-layer construction were

FIGURE 1
Two Sections of a Multi-layer Vessel Shown After 26 Layers Progressively Have Been Wrapped and Welded

FIGURE 2
The End of This Multi-Layer Shell Has Been Machined for the Welding Groove. This Shell Has a Total Wall Thickness of 5.3 In. Built of 26 Layers

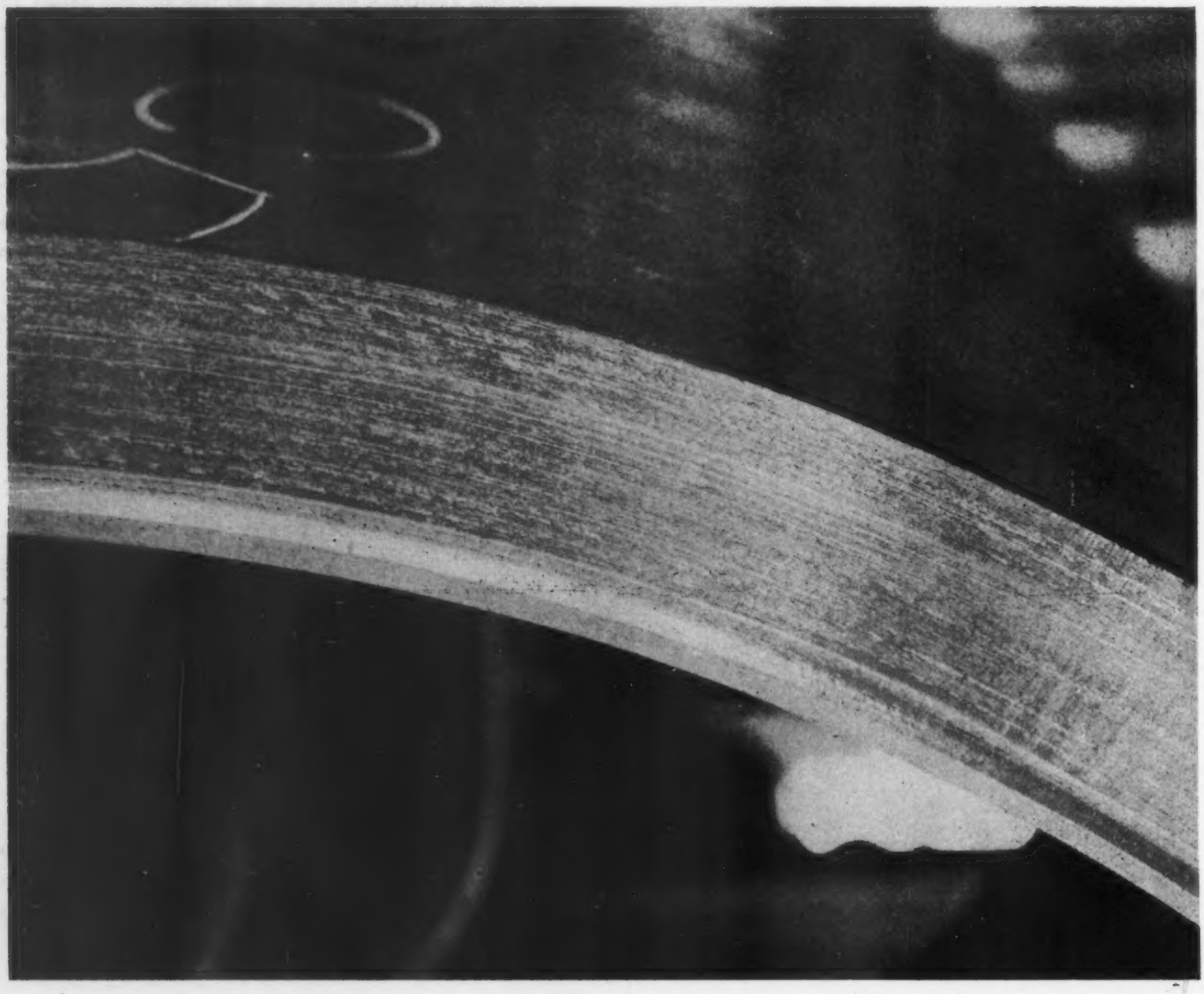


FIGURE 3
The Tight Fit Between Various Layers Is Apparent from This Close-up of a Multi-layer Shell

FIGURE 4

Tested to Destruction, This Multi-layer Vessel Failed Without Shattering and with a Considerable Amount of Deformation

FIGURE 5

These Are the Fragmented Pieces of a Solid-Wall Vessel Tested to Destruction. This Vessel Had an Outside Diameter of 33¼ Inches; Was 12 Feet Long, and 3⅝ Inches in Total Wall Thickness

FIGURE 6

This Is a Typical Multi-layer Test Vessel with a Large Flanged Opening in One Head

TABLE 1

Average Physical Properties of Steel in Two Vessels

Coupons from Vessel	0.2 Percent Set Yield Strength (Lb. Per Sq. In.)	Ultimate Yield Strength (Lb. Per Sq. In.)	Elongation in 8 In. (Percent)	Remarks
"A".....	39,770	58,845	29.5	Not stress-relieved
"B".....	37,670	56,260	32.3	Stress-relieved same as vessel "B"

TABLE 2

Stresses at Yield and Failure of Two Vessels

Vessel	0.2 Percent Yield by Water Column (Lb. Per Sq. In.)		Burst Point (Lb. Per Sq. In.)		Increase in Average Diameter at Failure (Inches)
	Pressure	Stress*	Pressure	Stress*	
"A"....	13,400	43,100	18,800	60,400	2.15 (not stress-relieved)
"B"....	11,500	37,000	17,375	55,900	3.54 (stress-relieved)

* By means of the formula $\frac{pDm}{2t}$

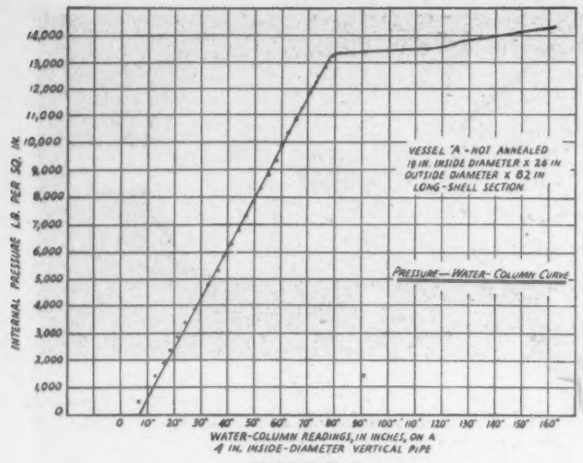


FIGURE 7

Graph Recording the Pressure—Water-Column Readings for Multi-layer Vessel "A" Which Was Not Annealed

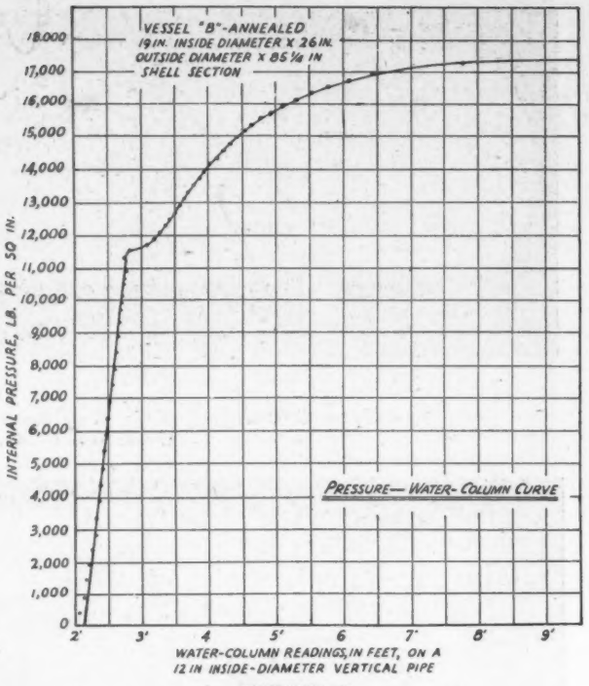


FIGURE 8

Graph Recording the Pressure—Water-Column Readings for Multi-layer Vessel "B" Which Was Annealed

built for destruction tests, and provided with reinforced openings in the cylinder and in one head. The cylinder and heads of these vessels were constructed of 12 layers of steel of varying thicknesses totaling about 3.85 inches. The vessels had an outside diameter of 27 inches, and were about 9 feet between heads. When tested to destruction, they failed at hydraulic pressures of 19,100 and 20,200 pounds per square inch, respectively. According to the common formula $\frac{pDm}{2t}$, these pressures correspond to maximum stresses of 58,000 and 62,000 pounds per square inch, respectively. Both vessels were made of ordinary boiler-steel plates, Figure 4, showing the rupture in one of these test vessels, reveals a failure strikingly different from those which occurred in the four solid-wall vessels. Failure occurred in the multi-layer vessels without any shattering or fragmentation, and with a considerable amount of deformation. The thick solid-wall vessels, however,

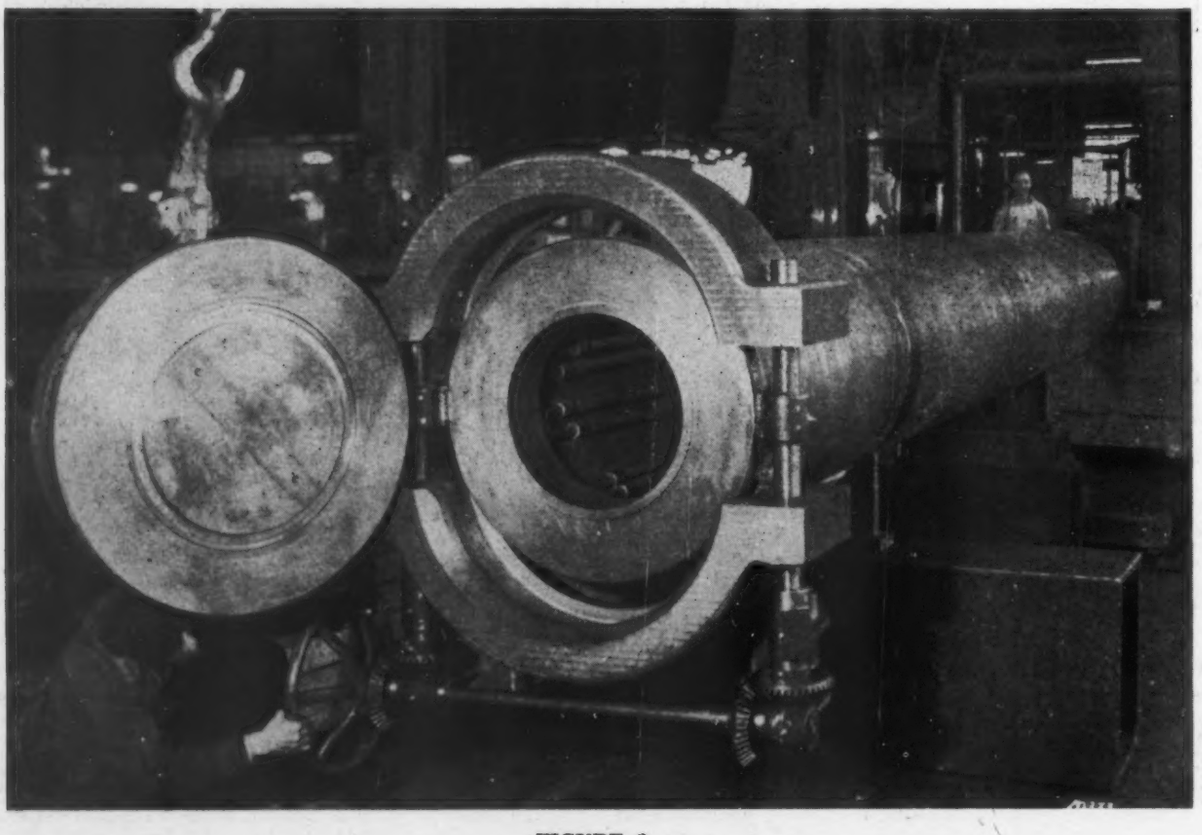


FIGURE 9

Multi-layer Vessel Now Operating Under a Pressure of 5,000 Pounds Per Square Inch. Note the Special Quick-opening Head

FIGURE 10

Here an Accumulator of Multi-layer Construction Is being Tested at a Pressure of 6,500 Pounds Per Square Inch. It Weighs 94,000 Pounds

failed with no measurable stretch or deformation; and they fragmented very badly, as shown in Figure 5.

In 1937 two additional layer vessels were tested to destruction to establish further information on the design of large openings and on the effect of stress-relieving temperatures upon layer vessels. Both were built of 12 layers, ¼ inch in thickness, wrapped around an inside layer ½ inch in thickness, giving the vessel a total wall thickness of 3½ inches. Both vessels had an outside diameter of 26 inches, and were 8 feet 8 inches in over-all length. They were built of layers which came from identical sheets of steel. These sheets were split in two in our own plant. One-half of each sheet was used in vessel "A" and the other half in vessel "B" in identical positions. Vessel "A," however, was not stress-relieved, whereas vessel "B" was stress-relieved at 1,150° F. The stress-relieving temperature in vessel "B" was held for 3½ hours; then it was cooled at a rate of 80° F. per hour. Figure 6 shows one of the vessels. The average physical properties of the steel in the two vessels, determined by test coupons cut from each plate, were as shown in Table 1.

The pressure-water-column readings for vessels "A" and "B" are shown in Figures 7 and 8.

The pressures and stresses at which the yielding and failure of the two vessels occurred are shown in Table 2.

It should be pointed out that the stresses at yield and failure shown for vessel "B" are very close to the yield and ultimate strength of the steel tested independently after it had been stress-relieved. On the other hand, the stresses at yield and failure for vessel "A" are somewhat higher than the yield and ultimate strength for the steel in the corresponding state. It is believed that this is due to the effect of the imposition of compressive stresses on the inside layers, with corresponding tensile stresses on the outside layers during the construction of the vessels, and these were not affected by stress-relieving in vessel "A." Inasmuch as the outside layers take on load less rapidly than the inside layers, it is to be expected that higher values might be shown by vessel "A" than by vessel "B," which has had these compressive construction stresses, as well as the strength of the steel, reduced by the stress-relieving operation.

We, therefore, do not advocate stress-relieving these vessels, and to date have never done so. It has been shown quite definitely that when at least one of the surfaces to be welded is made up of a multiplicity of

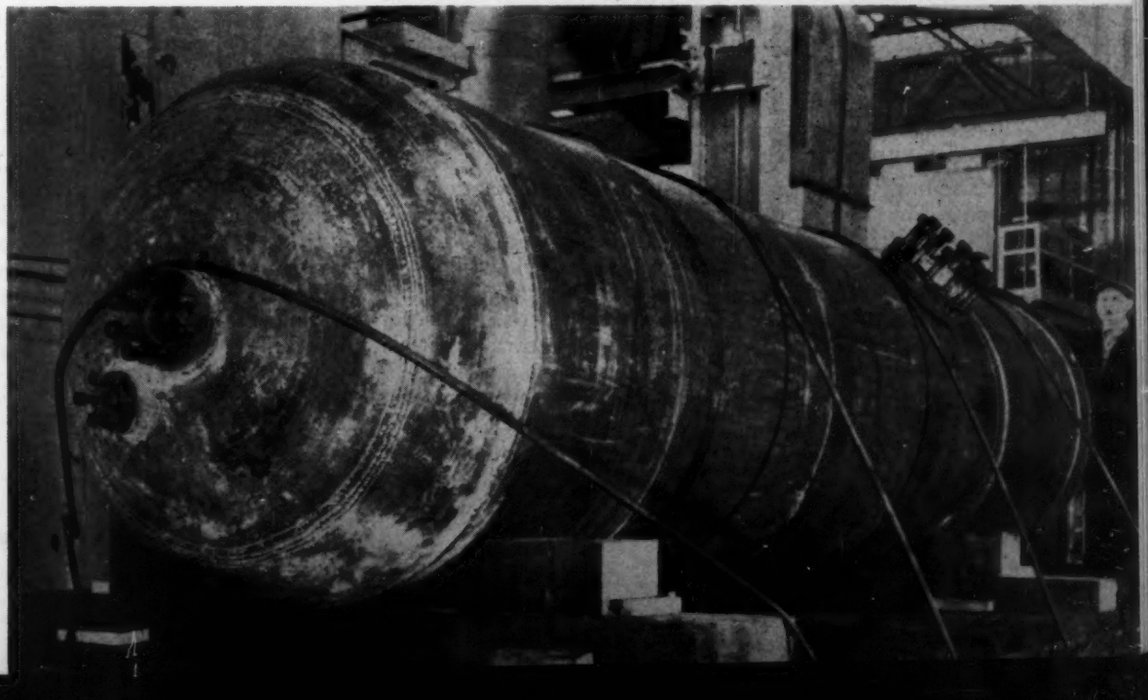


FIGURE 11

This Multi-layer Gas Separator is Now in Service in the Operation of Oil Wells

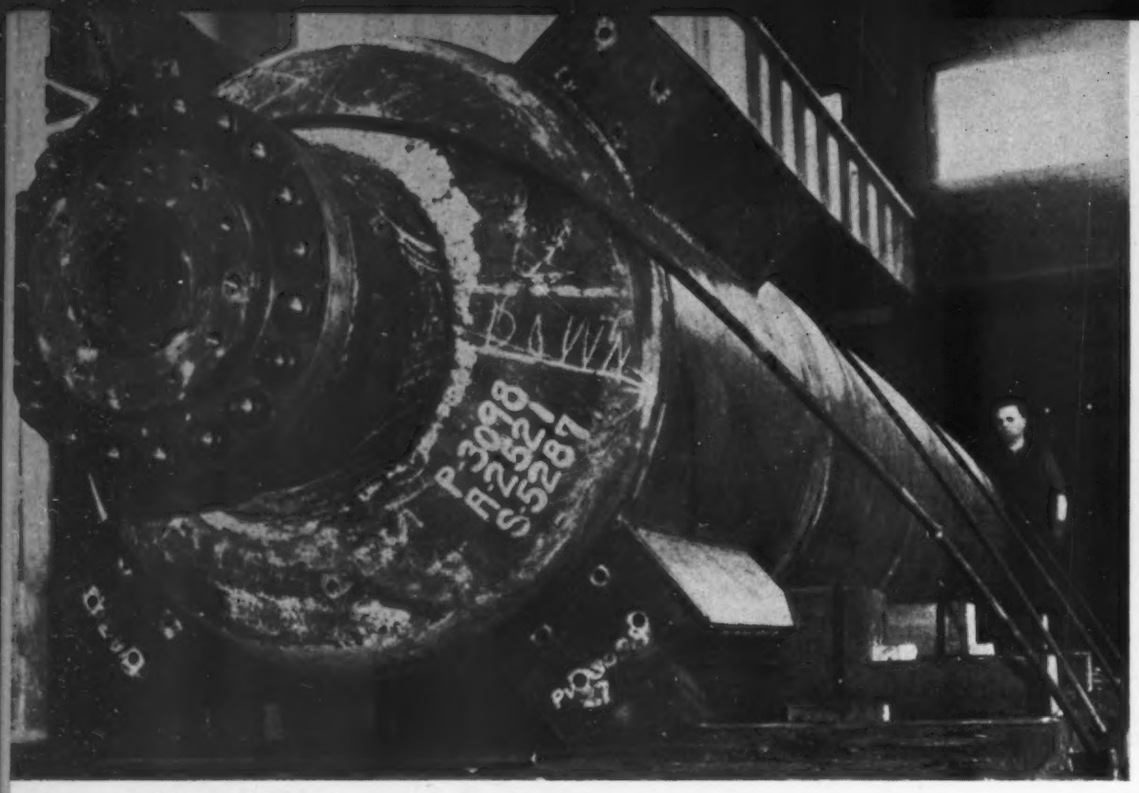


FIGURE 12

Built for a Steel Mill Descaling Unit, This Multi-layer Hydraulic Accumulator Has an Outside Diameter of 55½ Inches and Operates at a Pressure of 1,560 Pounds Per Square Inch

layers, the circular joints do not and cannot set up internal stresses that would make stress-relieving necessary.

On the basis of the foregoing tests, a considerable number of multi-layer vessels have been built and put into service. The first of these vessels for service was built in 1931, and has operated since that time at a pressure of 2,000 pounds per square inch. Figure 9 shows a vessel with an outside diameter of 28¾ inches; which is 21 feet 8 inches in over-all length, by 3⅞ inch total wall thickness, with a special quick-opening head. This vessel operates in rapid heating and cooling cycles, and at a pressure of 5,000 pounds per square inch. Figure 10 shows an accumulator under a test pressure of 6,500 pounds per square inch. This vessel weighs 94,000 pounds. It has an outside diameter of 56.6 inches; is 30 feet 9 inches in over-all length, by 5.3 inches total wall thickness. It is operating now at a pressure of 3,250 pounds per square inch. Figure 11 shows a gas separator for use in the operation of oil wells. This separator operates at a pressure of 2,000 pounds per square inch; has an outside diameter of 62 inches, and is 19 feet 8 inches in over-all length. Figure 12 shows a vessel with an outside diameter of 55½ inches, and which is 27 feet 9 inches in over-all length, by 2¾ inches total wall thickness. It operates at a pressure of 1,560 pounds per square inch.

These vessels now are in service for hydrogenation at high temperatures, gas separation, high-pressure chemical processes, high-pressure hydraulic-press cylinders, high-pressure gas storage, and high-pressure air-liquid accumulators.

The multi-layer vessel has a number of attractive features. The type of construction gives it wide flexibility with which it can overcome the present limits of size and weight in the construction of thick single-piece equipment for high pressures. The minute scrutiny which can be given the thin layers of steel which enter the fabrication of such vessels is bound to reflect itself in the quality of the product. Extremely important is the fact that the inner layer can be of any corrosion-resistant material, no matter how costly; whereas the outer, load-carrying layers can be of the most economical material for the resistance of the pressures and temperatures of operation.

The lower cost of equipment necessary for the fabrication of the multi-layer vessel gives it a further advantage in production cost over the thick solid-wall construction.

The API-ASME code recognizes multi-layer construction, and provides for its use in services when thick-wall pressure vessels are necessary. The ASME code has no provision for its application; and, as a matter of fact, in its present form would find great difficulty in accommodating this type of construction in its code set-up. Various states, however, which have laws covering design and construction of fired and unfired pressure vessels recognize its application and approve it for use.

This type of construction is not likely to replace the present large single-piece pressure vessels for ordinary refinery cracking units, because of its general cost.

On the other hand, the maximum weight of vessels which we have built by this method up to the present time is 110,000 pounds. Welded vessels of single-plate construction for relatively low-pressure operation have been built with a finished weight in excess of 400,000 pounds, so that we look to a great increase in possible weight of thick-wall multi-layer vessels and such weights as cannot be constructed in single castings or forgings.

SUMMARY

In summary, it should be pointed out that this type of vessel has been in severe service successfully since 1931. Its most valuable application is in the select high-pressure and high-temperature field which heretofore has been untouched, in which size and weight are vitally essential to economic production. It economically takes the place of the large thick-wall vessel, forged or cast, in sizes in which these methods of construction can be applied. Finally, its simplicity of construction means an earlier delivery date for the customer.

Metal Spray Protection of Refinery Equipment

CONTINENTAL Oil Company has had good success using the metal-spray process for the protection of refinery vessels against corrosion. Reaction chambers metallized with aluminum have suffered no measurable loss from corrosion in 4½ years, compared with a previous average annual loss of 0.036 inch.

The method also has been applied successfully in the economical restoration of pump rods and plungers. Other typical examples of successful applications are given. Examples of unsuccessful applications are included with a discussion of possible reasons for failure.

It is pointed out that the proper preparation of the surface to be metallized is the fundamental requirement for a successful metal-spray coating. The precautions to be observed in preparing the surface and in actually applying the coating are listed in detail.

This paper was presented at Ninth Mid-Year Meeting, American Petroleum Institute, at the Roosevelt Hotel, New Orleans, May 17, 1939.

IN VIEW of the reported waning enthusiasm of most refiners for the protection of refinery equipment by the metal-spray process, it may be of interest that Continental Oil Company has proved to its own satisfaction that metallizing can be utilized profitably.

In several respects our experience has paralleled that of many companies which have seen fit to abandon metallizing. When the first metallizing equipment was acquired in 1934, the corrosion technologist thought (or hoped) metallizing would have wide and almost universal application. Nearly everything was sprayed when there seemed to be a reasonable possibility of success. In the light of our present knowledge many of the resulting failures could have been foretold. On the other hand, our present knowledge of the limitations of metallizing came from careful observation of the various applications and study of case histories accumulated during those early days. There were a few successes; many failures. Profiting by careful examination of these failures, we now can consider metallizing for any particular application, and predict the result with reasonable certainty.

Knowledge of the important essentials required for successful metallizing may be obtained from published recommendations. We have found that meticulous attention to every detail is the only guaranty of complete success.

TYPICAL APPLICATIONS OF METALLIZING

Our experience with metallizing best may be shown by describing certain typical applications. Some of these were very successful, and others were either only partly successful or wholly unsuccessful. Some of our most important applications have been:

1. *Cracking-unit reaction chambers.*
2. *Dephlegmator towers, bubble towers, evaporators.*
3. *Lubricating-oil contact kettles.*
4. *Miscellaneous applications.*

There are certain precautionary measures which must be observed in metallizing the above types of equipment, because strict observance of these measures is essential to success. We have given a rather complete outline of the absolute essentials.

5. *Pump rods and plungers.*

Metallizing pump rods and plungers is somewhat different from metallizing the larger pieces of equipment mentioned in the above section. The difference is sufficient to justify establishing additional precautionary measures for successful metallizing of this smaller type of equipment.

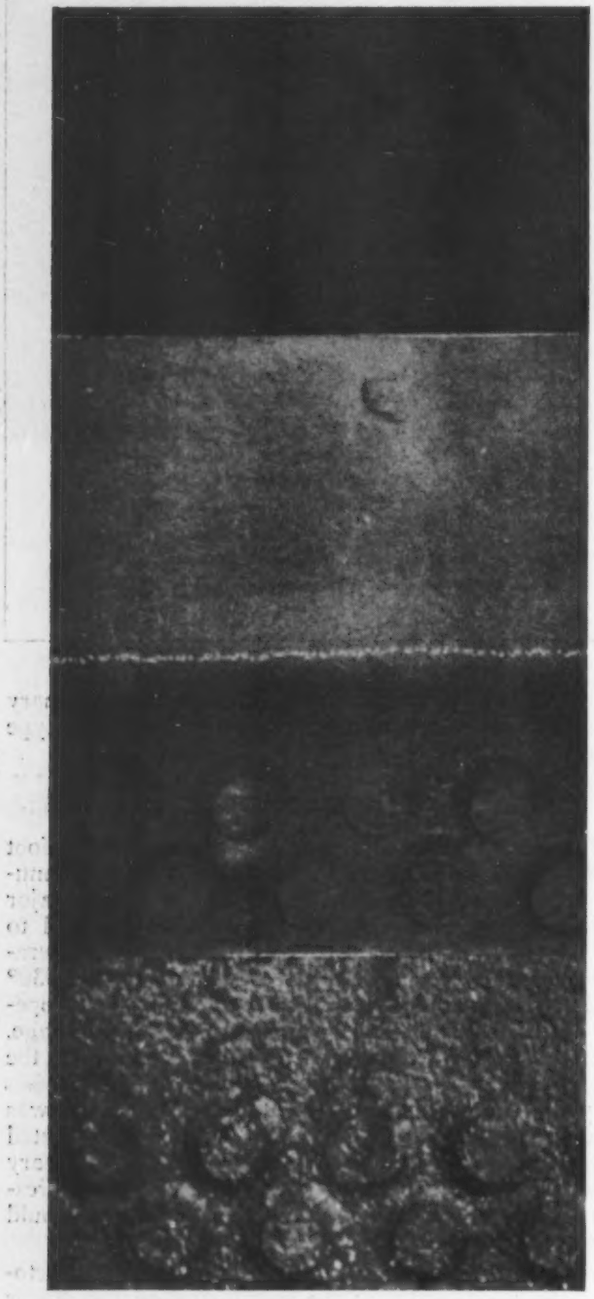
CRACKING-UNIT REACTION CHAMBERS

Metallizing the top rings and domes of two 10-foot by 40-foot reaction chambers on a Dubbs unit, in January 1934, was Continental Oil Company's first major project. Mid-Continent topped crude was charged to this unit in a non-residuum operation. The temperature of the oil stream entering the chambers was 930° F. The chambers had been designed originally to operate at a pressure of 250 pounds per square inch, gage. Over a period of four years prior to metallizing, the maximum corrosion rate observed was 0.050 inches per year, whereas the average rate for all chambers was 0.036 inches per year. Had corrosion not been arrested by some type of coating, it would have been necessary to replace the vessels some time ago, or to reduce pressure to such a point that operating efficiencies would have been impaired.

When the reaction chambers were inspected in October 1934, we found that the metallizing on the domes and the shells had been damaged. The metal-spray coat on the domes had peeled badly over a large portion of the entire dome area. We concluded that the peeling was due almost entirely to the fact that the original aluminum coat had been too thick. The damaged areas on the domes were sand-blasted and re-sprayed with only 10 coats of aluminum, with a total thickness of 0.018 inches.

The failure of the metallizing on the shells of the Dubbs reaction chambers may not have been like the dome failure. In an attempt to remove the coke from the metallized surfaces of the shells for inspection of the metallizing, the chamber was heated to dry and spall

the adhering coke. Subsequent inspection showed that the metallizing had been damaged somewhat, indicating that either too high a temperature had been used or that localized overheating had taken place during the spalling process. It was decided to sand-blast and metallize the damaged areas with 10 coats of aluminum to insure a satisfactory repair.



Lower: Original carbon-covered surface. Second: Carbon removed by blasting with river sand. Third: Surface fully cleaned by flint sand-blasting, ready for metallizing. Upper: Final surface metallized with aluminum. All pictures made with same exposure. Note that the sand-blasted iron appears lighter than the metallized surface. This is also true by visual examination.

FIGURE 1
Four Stages in the Metallizing of a Bubble Tower

When the thinner coating on the domes and shells was inspected six months later, it was found to be in good condition except for a small ring around each top manhole where most of the coating had been removed mechanically by the rotary cleaning equipment. In the case of the top rings, it was noticed that, in spots where the coating apparently had been destroyed by the rotary cleaning discs, it actually had been beaten into the steel. This was evidenced by the fact that the steel could not be electric-welded without first chipping or sand-blasting. It is believed that protection from corrosion is obtained even after the aluminum appears to be gone.

As a result of the final successful protection of the two original chambers, the remaining 10 Dubbs reaction chambers similarly were metallized with aluminum. In the 4½ years that have elapsed since the chambers were protected in this manner, there has been no measurable loss from corrosion.

Semi-annual inspection records on the 12 Dubbs reaction chambers show an average annual metallizing replacement of 4 to 5 percent of the total area originally coated. This replacement varies from as little as 1 percent to as much as 10 percent for individual chambers. As an example, the first chamber metallized has had 54 percent of the original coating replaced in five years. This percentage would be materially lower were it not for the fact that rotary cleaning equipment is employed in our particular case.

A typical example of metallizing failure was experienced in our East Coast refinery, when we attempted to metallize a reaction chamber. The chamber was part of a cracking unit processing high-sulfur gas oil at a temperature of 920° F. and at a pressure of 750 pounds per square inch, gage. The work was done by a local metallizing contractor. The coating was a complete failure within a few months. Inasmuch as numerous chambers operating under similar conditions had been metallized with complete success, we could attribute the failure only to faulty application. This may have been due to the effect of the high humidity prevailing at the time of metallizing. High humidity occurs during extended periods on the eastern seaboard, a factor that very easily could have been overlooked by an inexperienced contractor.

The obvious conclusion drawn from such an experience is that, if metallizing work is to be contracted, the qualifications of the contractor are extremely important. In case of doubt the purchaser should have a qualified inspector check the work in the field. We have found it advisable to do our own metallizing exclusively, but appreciate the fact that this may not be feasible for all companies.

DEPHLEGMATORS AND BUBBLE TOWERS

We have been successful in metallizing with aluminum the bottom sections of the six dephlegmator towers on our Dubbs cracking units. Over the period of 4½ years since metallizing there has been no measurable loss from corrosion.

After having convinced ourselves that we could apply aluminum successfully, we tried other metals when it was obvious that aluminum was unsuitable. It is to be remembered that almost any material which can be drawn into wire form can be sprayed with a metallizing gun.

In one of our refineries, the bubble tower of a cracking unit processing high-sulfur Southeast-New Mexico topped crude had lost metal at the rate of 0.129 inches a year by localized corrosion and erosion. The tower was metallized in the corrosive zone with 12 coats of 18-8 stainless steel to a thickness of 0.020 inches. In this case the use of aluminum would have meant certain failure because erosion was an important factor.

Two inspections following the installation of the liner

indicated that successful protection was being secured. In view of this successful application of 18-8 stainless-steel metallizing, we are proceeding to use that method of protection in similar locations at other refineries.

LUBRICATING-OIL CONTACT KETTLES

Our experience with the metallizing of a clay contact kettle in Ponca City serves as another example of metallizing which was not wholly successful. The kettles are used for mixing acid-treated lubricating oils with contact clay prior to processing the oils through a pipe still. Sulfur-dioxide corrosion, therefore, was involved. A new vessel was sprayed with red brass before installation. The metallizing was done under what we have learned since to have been unfavorable atmospheric conditions; viz., cold and damp weather. Even after 18 months' experience, we violated in this case one of the fundamental rules governing good metallizing practice. Inspection of the vessel after a little less than 2 years' service showed that the coating had disappeared completely over about 5 percent of the area, and much of the rest was blistered or actually starting to peel. When a good metallizing bond was secured, absolute protection had been afforded the parent metal. At the bare spots the loss of steel varied from 0.020 inches to 0.115 inches. The original thickness of the plate was 0.50 inches.

A new steel contact kettle in similar service had lost as much by general thinning after 1½ years as the metallized kettle had at localized spots in 2 years. The life of the unprotected kettle is estimated at 5½ years, as compared with an indefinite life for the metallized kettle—provided the metallizing is repaired periodically.

MISCELLANEOUS APPLICATIONS

In a similar manner we have been able to prevent corrosion and erosion by metallizing the surfaces of storage tanks; drums; ends of pipe-still tubes; exchanger-tube sheets, heads, and shells; and bull wheels on Duncan acid-sludge burners. For these purposes aluminum red brass, 18-8 stainless steel, and lead have been used.

IMPORTANT ESSENTIALS OF SUCCESSFUL METALLIZING

Preparing Surface

1. Sand-blast to pure base metal.

2. Direct-blast against metal at an angle of approximately 60 degrees to the surface.

3. Use first-quality blasting sand. We suggest No. 4 flint sand (dry-sacked). *Do not use ordinary river sand.*

4. Use dry air when sand-blasting.

5. Do not sand-blast large areas ahead of the metallizing operation. Even under the best of weather conditions, the area sand-blasted must not exceed that which can be sprayed during the same 8-hour shift in which blasting is done. In moderately humid weather it is necessary to metallize within 4 hours of sand-blasting.

6. When preparing surfaces which have been in previous service and on which coke or oil may be trapped in seams or under rivet heads, special care must be taken to remove such oil or coke. Heating with a torch is often necessary prior to sand-blasting.

7. Use dependable sand-blasting equipment.

Applying Metal Spray

1. Use dependable equipment. We use a standard metallizing gun which has been equipped with a modified atomizing tip of our design and manufacture.

2. The operator must be fully qualified both as to skill and personal reliability.

3. The metallizing gun must be supplied with absolutely dry air. It is sometimes necessary chemically to dry the air. A charcoal filter has proved satisfactory.

FIGURE 2
Operator Metallizing Bubble Tower Surface Shown in Figure 1.

4. The metal must be sprayed on uniformly. Wide variations in thickness of coating are conducive to failure. Best results have been secured when applying individual coats having thicknesses ranging between 0.0015 inches and 0.0020 inches. For example, when applying aluminum to a total thickness of 0.020 inches, 12 coats are sprayed.

5. Use only highest grade wire, paying particular attention to quality and diameter tolerances. It is economical to insist on wire sized to close tolerances, even though such wire may be priced at a premium. We have found, when using our modified gun, that 12-gage wire gives the best results—although we are now experimenting with 11-gage wire.

6. The rate of applying coatings can be varied within reasonable limits, but we have found the following to be optimum:

	(Pounds Per Hour)
Aluminum	1.2 to 1.8
High-carbon steel	3 to 4
Low-carbon steel	3 to 4
Lead	15 to 20
Monel Metal	2 to 2.5
Red Brass	3 to 4
Stainless steel (18-8)	3 to 4

7. Gas-pressure settings are important, and must be varied as a function of the melting points of metals sprayed, as follows:

8. All other mechanical work to be done in the zone

	Approximate Melting Point (Deg. F.)	Acetylene Pressure (Pounds)	Oxygen Pressure (Pounds)	Air Pressure (Pounds)
Aluminum	1,217	15	16	75
High-carbon steel	2,560	19	20	80
Low-carbon steel	2,680	19	20	80
Lead	620	13	14	75
Monel metal	2,460	24	25	80
Red brass	1,870	18	19	80
Stainless steel (18-8)	2,550	18	19	80

to be metallized should be completed before metal is sprayed.

9. Do not attempt to metallize when the relative humidity exceeds 60 percent.

10. Be sure that the freshly sand-blasted surface does not come in contact with anything moist or oily. There is a natural tendency to think that sand-blasting is merely to roughen the surface, and that the heat of the metallizing spray will remove the impurities. This is not the case; inasmuch as the temperature of the sprayed metal, when it strikes the surface, is estimated to be less than 200° F. When in doubt as to the cleanliness of surface, take no chances; sand-blast again.

METALLIZING OF PUMP RODS AND PLUNGERS

Metallizing of pump rods and plungers has furnished some of our best examples of the savings to be made by the use of the metal-spray process.

One refinery had been using 14-percent-chromium-stainless-steel plungers in a hot-oil pump. The rods were 60 inches long with an outside diameter of 5 inches and an inside diameter of 3¾ inches, and when new cost $300. These rods now are being made of low-carbon-steel tubing metallized with high carbon steel. The total cost is approximately $90, broken up as follows:

Welder	Labor	$ 8
Machining	Labor	10
	Material	14
Metallizing	Labor	21
	Material	12
Grinding	Labor	25
Total		$90

Experience indicates that the life of the metallized rod is as long, or longer, than that of the stainless-steel rod.

For a hot-oil pump at another refinery, new low-chromium-alloy-steel plungers, with an outside diameter of 3⅜ inches, an inside diameter of 1¾ inches, and 60 inches long, cost $126 each. These plungers were badly scored in one year of service. Three years ago a set of these plungers, too badly scored for further use, was built up with high-carbon steel by metallizing at a total cost of $53.50 each. The re-built plungers were in perfect condition at the time of the last inspection, which represented 2½ years' service.

It should be mentioned that in the smaller sizes the

FIGURE 3
Operator Building up Surface of a Worn Pump Plunger

cost of metallizing approaches that of new rods; and under certain circumstances the cost may be greater.

At first we attempted to build up pump rods by cutting 32 shallow threads to the inch and metallizing without sand-blasting. This method was unsuccessful. Complete success was obtained using 12 threads per inch, sand-blasting, and then metallizing.

The procedure employed in restoring a typical pump rod that has come into the shop for repair is as follows: Undercut rod 1/32 inch to 1/16 inch, depending on depth of scores. Cut 8 to 12 shallow threads per inch.

Sand-blast to roughen the surface thoroughly and to render it 100 percent clean. This freshly sand-blasted surface must not be touched with the hand nor handled in any way before metallizing.

The rod is chucked in the lathe and turned at a rate which will result in a peripheral speed of 30 feet per minute. The gun is supported 4 inches to 5 inches from the surface being metallized, and is moved laterally by the lathe carriage at a speed of 2½ to 3½ inches per minute.

In the beginning three light passes are applied the full length of the rod. The metal feed to the gun then is increased to a maximum deposit rate of 3 to 4 pounds of metal per hour.

The rod is built up to an oversize of 1/16 inch total diameter to take care of low spots. The total thickness used on an average rod will vary from 5/32 to 3/16 inch on the total diameter. The rod finally is ground—not machined—to finished dimensions.

It has been found essential that, when metallizing a pump rod, the work be continuous; i. e., the metallizing should be done immediately after sand-blasting; and once started, between coats it must not be left overnight nor for any other appreciable length of time. Any deviation from this rule invites failure.

COSTS

Our first aluminum metallizing cost approximately 80 cents per square foot of surface coated. A typical break-up of charges on a 400-square-foot project is as follows:

Labor	$130
Aluminum	43
Sand	40
Welding supplies	65
Handling charges	2
Transportation	10
Overhead	32
Total	$322

Current aluminum applications are being made at a unit cost of from 70 to 75 cents per square foot. Obviously, the cost of metallizing small areas is higher. For example, repair work will cost from $1.10 to $1.15 per square foot.

The cost for spraying the other metals will vary—depending on thickness of coating, cost of sprayed metal, and extent of surface covered. For example, we have applied lead coatings for as low as 70 cents per square foot—although the cost of 18-8 stainless-steel metallizing has been as high as $2.25 per square foot.

The Solutizer Process

(*Continued from page 176*)

and Newton[3] has resorted recently to the diazo reaction in an attempt to achieve this result.

With regard to the solutizer process, this apparent difficulty is overcome readily by using a mixed solutizer solution containing both *iso*butyrate and alkyl phenolate salts, and the treated gasoline then has a definite alkyl-phenol content, i. e., that which is in equilibrium with the alkyl phenolates in the solutized caustic phase. This is illustrated by laboratory data presented in Table 4.

The mixed solutizer solution has been tested in the pilot plant, and appears to be suitable also for commercial application. If the incoming gasoline has a high alkyl-phenol content, it is feasible to pre-treat first with fairly strong sodium hydroxide (15 to 40 degrees Baume) in order to remove the bulk of the alkyl phenols, and these then may be recovered separately and utilized as gum inhibitors or for other purposes. If the incoming gasoline, however, contains no alkyl phenols (which is the case for straight-run products and for cracked-gasoline fractions with an end point below approximately 300° F.) it appears advantageous to use only *iso*butyrate as a solutizer. No oxidation inhibitors are required with straight-run materials; and the low-boiling cracked fractions may be inhibited following the solutizer treatment, or they may be blended with a gasoline which does contain inhibitors.

TABLE 4

Effect of Solutizer Treatment on the Removal of Natural Inhibitors from an Acid-treated Full-Range Cracked Gasoline

Type of Solutizer Solution Used	Induction Period of the Treated Gasoline at 100 ° C. and 100 Lb. Oxygen* (Hours)
None—(sour gasoline)	6.00
Isobutyrate solutizer	0.33
Isobutyrate–alkyl-phenolate solutizer	4.08

* The induction period serves as a measure of the natural-inhibitor content of the gasoline.

PRESENT STATUS OF THE PROCESS

In conclusion, it may be said that the solutizer process has reached the stage, both in the laboratory and in the pilot plant, where it is ready for commercial application. At the present time a full-scale plant with a daily capacity of approximately 7,000 barrels is being designed to sweeten a high-sulfur cracked-gasoline fraction initially containing 0.36 percent mercaptan sulfur.

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Lighting of Refineries and Refinery Equipment

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THE subject of adequate lighting for refineries and refinery equipment is rather broad, and no attempt will be made to cover this subject in detail. The scope of this article will be limited in a very general way as to what is considered good practice from the standpoint of efficient illumination in refineries, with due consideration being given to safeguarding of persons from electrical hazards and protection of buildings and equipment from possible fire or explosion hazards.

This paper was presented at Ninth Mid-Year Meeting, American Petroleum Institute, at the Roosevelt Hotel, New Orleans, May 17, 1939.

MANY people not familiar with refinery operations are of the opinion that due to the highly-flammable liquid handled, every location within a refinery constitutes a definite fire hazard, but such is not the case. A refinery may be divided into three classes, viz.: non-hazardous, semi-hazardous, and hazardous locations. Each of these classes will be considered in further detail later in this discussion.

NON-HAZARDOUS LOCATIONS

In general, all lighting systems should be installed in accordance with the latest edition of the *National Electric Code,* and should comply also with any local code or ordinance whenever such inspections are required. Conduit wiring should be adhered to for permanent installations, inasmuch as this type of installation will meet the necessary requirements for all three classes of locations.

Lighting panels should be located as near as is practicable to the load centers. The number of branch circuits and the number of outlets per circuit should be governed by local conditions, wherein provision should be made, in event of circuit failure, for a reasonable amount of illumination.

At some locations the range of intensity generally considered to be good practice is:

For office lighting, from 25- to 35-foot candles.

For control rooms, from 10- to 15-foot candles.

For pump houses, from 5- to 10-foot candles.

For platforms and walkways, from 1- to 2-foot candles.

There are numerous locations in a refinery that could be given ratings other than those mentioned, but these will serve to indicate the amount of illumination that is considered good practice.

At some locations, a combination of small lighting units used in conjunction with floodlights provides satisfactory illumination when a large area is lighted. The individual small units serve to dissipate sharp shadows, which is one of the prime requisites of good illumination.

Lighting fixtures should be cleaned periodically, regardless of type or location; as this will increase materially the efficiency of the individual lighting units.

Series or multiple yard lighting, floodlighting, or a combination of these will provide suitable yard lighting for roadways, tank farms, and similar non-hazardous areas. When a large number of lighting units is involved, it no doubt will be more economical to install a series lighting system with centralized control rather than a multiple system with control switches scattered about the plant. However, the multiple system in some instances is satisfactory in small plants.

Floodlighting of areas around operating units has been found to be very satisfactory, as well as economical, when fairly good lilumination is required. Floodlighting may be used to good advantage in other areas in which fairly good illumination is required, and little trouble is encountered due to shadows from other operating equipment. However, as mentioned previously, smaller units can be used readily to eliminate sharp shadows.

In the past few years there has been a large improvement in the design of fixtures for office lighting. Several manufacturers have placed on the market various types of indirect and semi-indirect lighting fixtures which are very satisfactory for office lighting. These indirect lighting fixtures give good distribution and a minimum amount of glare—both very essential features for good office lighting.

Open-type industrial fixtures of the approved design may be used in non-hazardous areas, such as in warehouses or boiler houses, and on certain operating units that do not handle highly-flammable products.

SEMI-HAZARDOUS LOCATIONS

In some instances it is difficult to make a definite decision as to whether a location should be considered hazardous or semi-hazardous, due to the kind of products handled, or on account of close proximity to operating units handling fiammable products.

Although it is realized that explosion-proof lighting systems require a considerably higher investment than regular vaporproof installations, if there is any possible question about whether a location is hazardous, the

higher investment is considered justified. With a vaporproof installation it is necessary to maintain properly the gaskets and globes in order to be safe for even a semi-hazardous location.

It is the opinion of some in the industry that vaporproof fixtures, when mounted at a suitable height above ground, would be satisfactory; for it is the theory that vapors have a tendency to remain near the ground, and at higher altitudes better circulation of air is obtained and vapors are dissipated. Conduit systems for vaporproof installations should be sealed properly in order to prevent gases from entering enclosures such as switches, lighting fixtures, etc.

It is necessary from time to time to make a decision as to replacement of vaporproof lighting fixtures with a complete explosion-proof system at certain locations that may be regarded as hazardous. In most cases the original vaporproof installations have been in service for years without any trouble being experienced. It is difficult to reach a decision as to whether the new investment is justified, even though it is conceded that the location is considered hazardous. Such installations should receive individual consideration by a safety committee. If a location actually is considered a definite hazard, a complete explosion-proof system should be installed; otherwise such changes and alterations should be made in order to reduce the fire hazard to a minimum.

The explosion-proof line of fixtures and fittings has been developed quite extensively in the past several years. Most of this equipment bears underwriters' labels for class I, group D, service. Explosion-proof lighting fixtures are inefficient from the standpoint of optimum lighting. This is due to the type of construction necessary to meet the requirements for this class of service. As a result, larger-wattage fixtures or more units should be installed in order to obtain a foot-candle output comparable with the open-type fixtures.

Lighting panels for hazardous locations should be of a design suitable for class I, group D, service. Sealing condulets should be installed on each side of arcing parts, and lighting fixtures should be equipped with sealing compartments. This arrangement will prevent gases from following the conduit system to enclosures having arcing contacts.

HAZARDOUS LOCATIONS

There are quite a few locations in a refinery such as steam stills, light-oil agitators, stabilizers, control houses, etc., that are considered hazardous locations. At these locations it is recommended definitely that an explosion-proof lighting system be installed. There are some locations that might be considered border-line cases as to whether they should come under the classification of hazardous or semi-hazardous locations, and in that event the decision should be made by some safety committee. Inasmuch as the item for lighting on these projects is usually very small as compared with the total investment involved, it might be considered good practice to make an explosion-proof installation whenever there is any question of doubt. Such installations have the added advantage that if conditions should develop later wherein the location might be considered as definitely hazardous, the explosion-proof installation adequately will meet the requirements.

Some mention should be made at this time of the use of portable lamps in hazardous or semi-hazardous locations. This practice should be discouraged as much as possible, due to the hazard involved. Regardless of the care taken in providing proper materials for extension cords, there is always the question of the human element, as well as the chance that such equipment may become unsafe shortly after having been placed in service.

The use of low voltage for extension-cord service is favored by some companies—more from the standpoint of safeguarding against personal injury than from an explosion or fire-protection angle.

CONCLUSION

In conclusion, it might be stated that these remarks have been more or less general in regard to lighting of refineries and refinery equipment. In order to obtain the best installation from the standpoint of adequate distribution and minimum glare, it is necessary to design the lighting facilities for each individual operating unit separately, as each installation presents separate and distinct problems. The first question to decide before starting actual design is under what classification a particular installation comes, and then proceed with the design in accordance with good practice—both from the standpoint of distribution and the selection of materials for particular service requirements.

Measurement and Regulation of Production *from Unusually High Pressure Gas Wells*

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THE measurement of high-pressure gas will be discussed in two parts. The first part will deal with the measurement of a dry gas which, if subjected to moderate changes in temperature and pressure, will still remain a gas. The second part will consider the measurement of a wet gas which carries some entrained liquid and would yield a distillate upon reductions of temperature and pressure.

Dry-gas measurement does not present the difficulties that are involved in wet-gas measurement and will be discussed first. Dry gas at extremely high pressures can be metered accurately in a manner similar to gas at low pressures. The only difference is in the magnitude of the gas law deviations. The specific gravity of the gas can be determined by the conventional gravity balance method. Coefficient correction factors are available in all meter books.

GAS LAW DEVIATION

As we all know, hydrocarbon gases at high pressures do not obey Boyle's law. The deviations become very large in certain cases and cannot be neglected in computing orifice coefficients. The compression of a gas at constant temperature causes an increase in its density. The actual increase is greater than that calculated from the gas laws. Because the actual density is greater than the calculated value, the resulting actual volume is less than that calculated by Boyle's law. This deviation in density is a maximum in the vicinity of 2500 pounds per square inch and above that decreases to almost nothing in the vicinity of 5000 pounds per square inch.

Conversely, a gas which has already been compressed at high pressures, will, upon expansion at constant temperature, give a volume larger than that expected from calculations by Boyle's law. This deviation can be corrected by a factor which we commonly call in gas measurement, the super-expansibility factor. The reciprocal of this super-expansibility factor can be referred to as the super-compressibility factor. A series of curves (Figure 1) for the super-compressibility factor for pure methane are shown. Naturally-occurring hydrocarbon gases follow this general trend of curves. The magnitude of deviation depends upon the composition of the gas because the heavier hydrocarbons have higher compressibilities. It can be seen from the curves that temperature has quite a pronounced effect upon these compressibility factors.

As previously mentioned, a gas which has been compressed to a high pressure, upon expansion at constant temperature, results in a volume larger than would be expected. The gas, therefore, acts as if it were originally under a higher pressure than that used in computing its volume from Boyle's law. The basic orifice equation is:

$$Q_h = C' \sqrt{h_w P_f}$$

Where— Q_h = Volume of gas per unit time.
C' = Orifice factor made up of general constants.
h_w = Head in inches of water.
P_f = Absolute pressure of flowing gas.

Since the gas behaves as if it were under some higher pressure, a correction factor must be applied to raise the actual pressure (P_f) to this higher effective pressure. This factor is usually called a "Y factor" and it is the reciprocal of the value Z shown on the deviation curves for methane:

$$Y = \frac{1}{Z} \qquad \text{Where } Z = \frac{PV}{P_o V_1}$$

The common procedure adopted in the orifice meter books is to apply this "Y factor" to P_f as a separate correction factor. Since the pressure, P_f, appears under the square-root radical, any correction will naturally be a square-root factor. Therefore, the square root of Y is introduced as a separate correction and is usually denoted by F_{pv} in the orifice-meter equation.

Several methods can be used for determining the Value Z and, in turn, the value F_{pv}. The most convenient method for dry gas is that devised by H. S. Bean.[1] In his procedure, a gas to be measured, is compressed in a cylinder to the desired pressure and maintained at line temperature. A dead-weight tester is used to measure the pressure of the gas in the cylinder. "After a sample of the gas has been collected at high pressure in a steel cylinder of known capacity, successive small portions of the sample are withdrawn into a glass burette where their volumes can be determined at atmospheric pressure. This is continued until the whole sample has been reduced to atmospheric pressure, and the sum of all the volumes at atmospheric pressure is then compared with the volume to which the initial known volume of gas would have expanded if it had been reduced to atmospheric pressure in accordance with Boyle's law." A curve of Z versus pressure can be plotted.

For greater speed and convenience, in our own laboratories, we measure the expanded gas in a very accurate wet-test meter instead of in the burettes. The general procedure is substantially the same as that devised by Bean except that a water vapor

*Presented at Southwestern Gas Measurement Short Course, University of Oklahoma, Norman, Oklahoma, April 22, 1939.

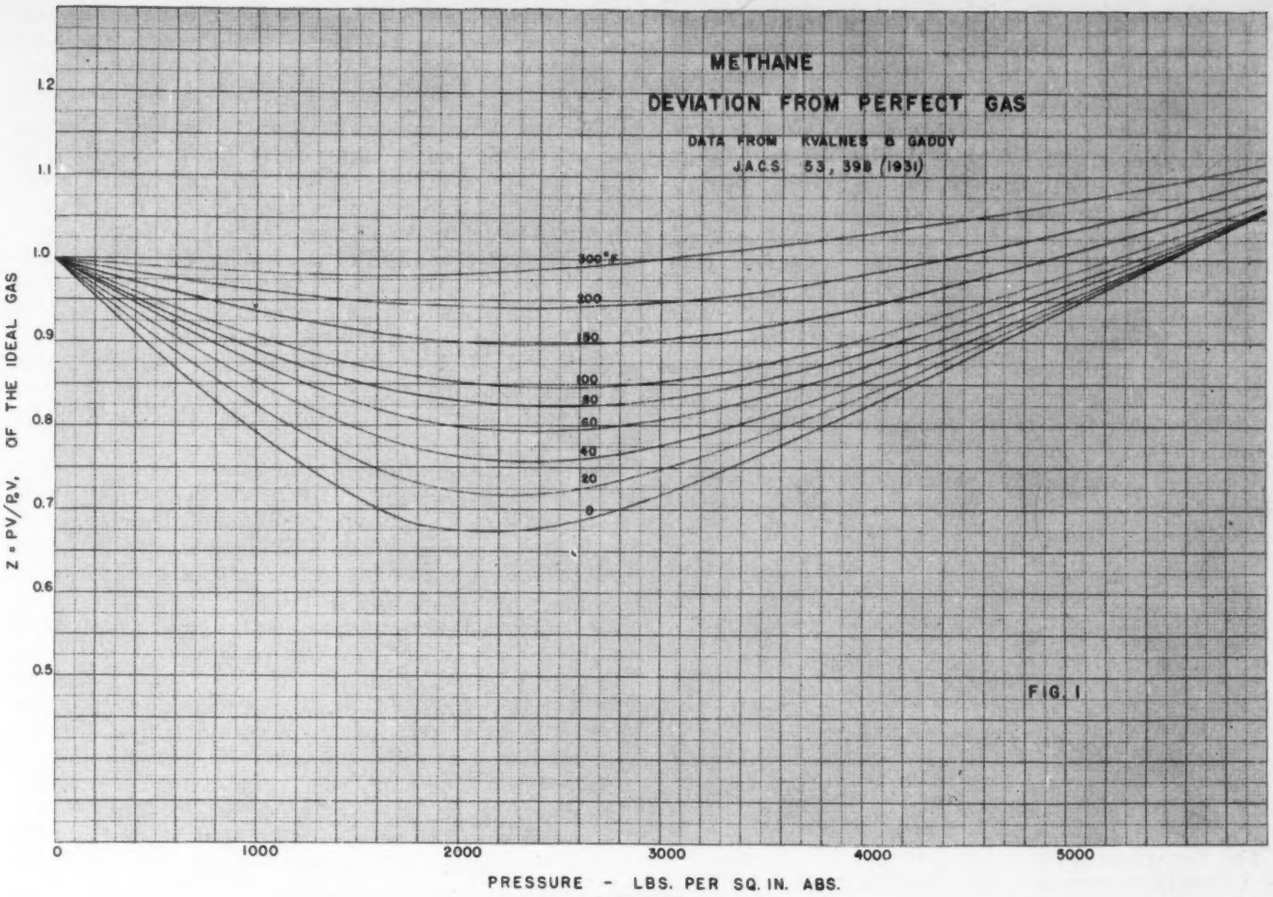

FIGURE 1

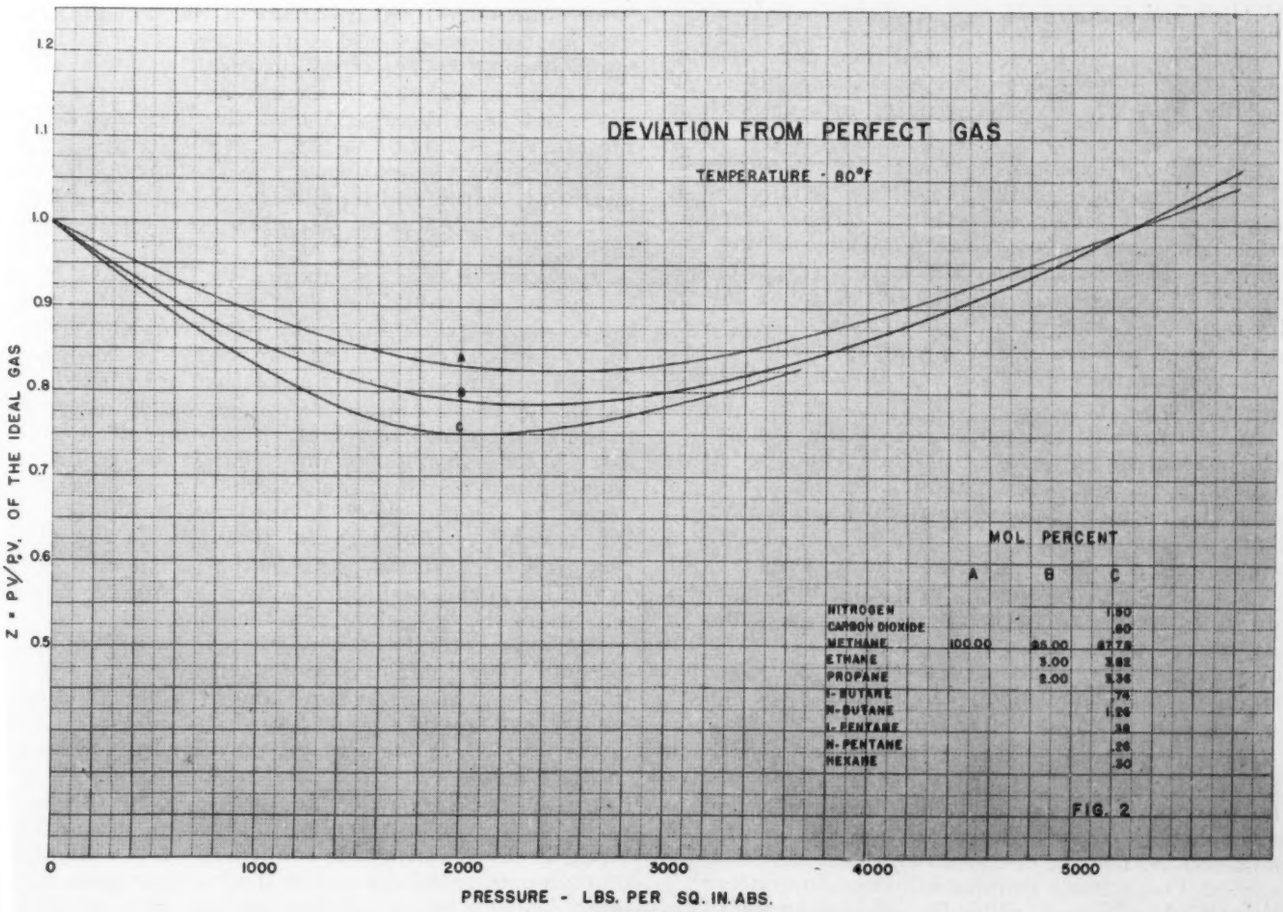

FIGURE 2

pressure correction is necessary. A deviation curve obtained in this manner (Figure 2) is shown on a residue gas of 95 percent methane, 3 percent ethane and 2 percent propane.

W. K. Lewis[2] showed that it was possible to correlate the deviations of pure hydrocarbon gas as functions of reduced temperatures and pressures. Curves of this correlation are published. Kay[9] developed for gaseous hydrocarbon mixtures, a concept of pseudo-critical temperatures and presures from which, with the generalized correlation of Lewis, it is possible to calculate the deviations of naturally occurring hydrocarbon gases from their analyses. Expasibility factors compiled from these data are good in the absence of exact experimental data and can be used where it is impossible to actually determine the Z versus pressure curves.

Sage and Lacey[3] have determined the compressibility factors Z for a natural gas of the following composition (Figure 2):

Nitrogen	1.50
Carbon Dioxide	.60
Methane	87.78
Ethane	3.82
Propane	3.36
Iso-Butane	.74
N-Butane	1.26
Iso-Pentane	.38
N-Pentane	.26
Hexane	.30
	100.00

The deviation factors for this gas are greater by an appreciable amount than those for pure methane. They are also greater than those for the residue gas which we determined in our laboratory. The difference in factors are thus dependent enough upon the composition of the gas to warrant their experimental determination for the gas in question. This is especially true where very accurate measurement is desired.

The above discussion deals with the measurement of gas by an orifice meter. It might be mentioned at this point that very good results are being obtained in certain places in recycling plants by letting the cylinders of the compressor act as a displacement meter. The particular installation in mind injects dry residue gas back into the formation at a pressure in the neighborhood of 3500 pounds per square inch. Pulsation in the flow line make orifice metering impossible.

An instrument has been placed on the compressor which records the strokes of the cylinders. From shop data, the compressor manufacturer has worked out a displacement volume for the pistons per stroke. Thus, an engine making a given number of strokes or revolutions a day displaces a definite given volume of gas. This gas volume at operating temperatures can be converted to its volume at 60°F. and also to any desired pressure base by suitable super-expansibility factors. In such a case, the Y factor is applied directly to the volume displaced instead of the square root of Y as in orifice meter work.

The gas volume measured in this way has been periodically checked against the metered volume of the compressed gas after it has been expanded to atmospheric pressure, the expansion eliminating all pulsation. So far, the operators are pleased with their results. There is no definite information concerning the actual accuracy of such measurements. This would depend almost entirely on the conditions of the piston rings and cylinder walls of the compressors.

WET GAS

The problems encountered in measuring wet gas are numerous and in many cases, hard to combat. In 1932, Dr. W. N. Lacey stated that the distillate obtained from a well which is now referred to as a gas-distillate well, might actually be a gas in the reservoir. The large amount of work which has since been carried out substantiates this view, and it is now known that this distillate was originally a part of the gas phase within the reservoir.

Before discussing the metering of gas from a well of the gas-distillate type, a study of the causes and effects of liquid condensation from the gas will be given.

A brief explanation of the phase relations of a sub-surface gas (Figure 3) may aid in understanding the behavior of a gas when subjected to changes in pressure or temperature. This diagram is not exact in its dimensions, but merely shows a general trend toward which naturally occurring hydrocarbon mixtures adhere. Definite experimental curves have been published by Lacey and his co-workers[4] and from his data together with that by Kay[5] and Katz[6] we can arrive at some conclusion as to the shape of the diagrammatical relations of a complex hydrocarbon system. The portion of the curve AC is the boundary between the single phase or liquid region and the two-phase or vapor and liquid region. This line is the vapor pressure or bubble point line. The line CB is the boundary between the same two-phase region of vapor and liqud on the inside and the single phase vapor region on the outside. This line is called the "dew point curve." At the point C, we have the critical point where the properties of the vapor and the liquid become continuously identical, and they cannot be distinguished from each other.

We now have three sections of this diagram: above the line AC is liquid; to the right of C and outside of CB is pure vapor; and, inside the line ACB is a mixture of vapor and liquid. The dotted lines represent the percentage of liquid in the liquid-vapor region.

Wells of the type exemplified by the Texas Panhandle district would have reservoir conditions falling to the lower right of the dew-point curve CB, shown by the point X^1. As can readily be seen, any change in pressure would not affect the phase behavior of this fluid because throughout any pressure range at the given temperature the fluid always remans a gas. Any appreciable temperature reduction would, however, cause the condensation of liquid because the conditions would then fall to the left of the dew-point curve CB and would lie in the two-phase region. Practically all of the recent gas wells in the Texas and Louisiana Gulf Coast produce liquid and are of the type shown by the point X.

We have recently learned that wells of the gas-distillate type contain, in the reservoir, a gas which from subsurface temperature and pressure measurements, is shown by a point X or on the upper portion of the line CB. If the pressure on this gas is allowed to drop, it will cause the condensation of liquid because the pressure will now be at a point P which is in the two-phase region. This condensation of liquid is called retrograde condensation. A reduction of temperature of the gas will also have the same effect because we would drop to a point T which is

also in the two-phase region. A combination of these two factors, pressure and temperature reduction, results in a condition shown by Y and is therefore to be avoiled in all cases if we expect to have a true gas flowing from the well head.

Of course, it is impossible to flow a well without some reduction of pressure of temperature from that in the subsurface formation and consequently most wells do carry a certain small amount of entrained liquid. The amount of this entrainment which can in some cases cause slugging, will depend upon magnitude of the pressure and temperature reductions.

For this reason, we think it is very advisable to install chokes downstream from the meters. Such a procedure will result in a minimum of retrograde condensation and the fluid passing thhrough an orifie will very nearly have the properties of a true gas.

An anlysis of the distillate trapped out of the flow line of a well enables us to calculate the error involved as a result of retrograde condensation.

	Mol. %
Methane	29.50
Ethane	4.33
Propane	5.24
Iso-Butane	2.37
N-Butane	4.05
Iso-Pentane	3.67
N-Pentane	2.44
Hexane	10.22
Heptane +	38.80
	100.00

Assuming that we obtained .2 gallons of liquid of the above composition, we can convert it to actual vapor which would be .56 cubic feet per 100 cubic feet of residual gas. The error thus involved is

$$\frac{100 \times .56}{100.56} = .56\%$$

Such an error could not be considered appreciable.

Whether or not a small amount of liquid entrainment actually interferes with the correct flow of a vapor through an orifice, is a subject for considerable thought. We must, however, keep in mind that at pressures near 3000 pounds per square inch the physical properties of the gas begin to approach those of a liquid, and it does not seem probable that so small a volume of liquid entrainment could appreciably interfere with measurement by the orifice.

If gas from a gas-distillate well is passed into a gravity balance, liquid will condense in the balance and connection lines due to the drop in pressure. The results of any specific gravity balance determi-

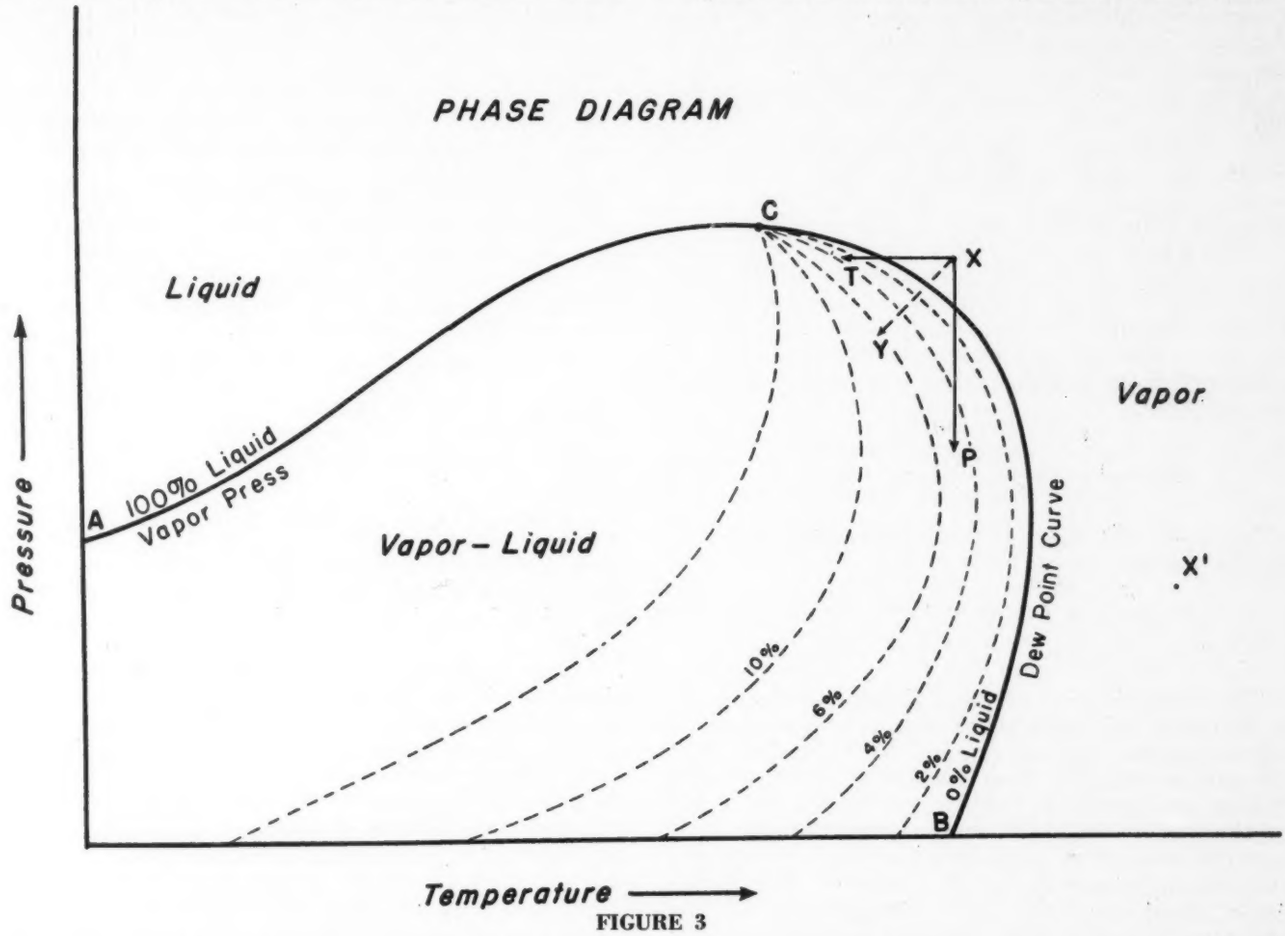

FIGURE 3

FIGURE 4

Separator Pressure—Pounds Per Square Inch	1400 lbs.	2000 lbs.	2400 lbs.
Methane	92.00	91.04	91.02
Ethane	5.87	5.48	5.00
Propane	1.05	1.70	1.70
Iso-Butane	.28	.43	.45
Butane	.29	.48	.53
Iso-Pentane	.10	.17	.30
Pentane	.09	.17	.17
Hexane	.15	.21	.40
Heptane	.17	.32	.43
	100.00	100.00	100.00
Calculated Sp. Gr	.612	.632	.642

nation will, therefore, be low, depending upon how much liquid has condensed. An example of such an error is shown by the following. These analyses are of gases from a separator while it was operating at various pressures. The temperature in all three cases was very nearly the same.

The variation shown in the specific gravities of the gas will result in quite a difference in F_g factors in the orifice coefficient. For very accurate measurement, a hydrocarbon analysis of the gas would, perhaps, enable us to calculate the specific gravity to a greater degree of accuracy than could be determined in the balance.

The same errors are involved in determining the expansibility factor for a gas of this type. Liquid will condense in both the high-pressure cylinder and in the burette as the gas is expanded for measurement. A little different method can be used here for arriving at an F_{pv} factor.

If we obtain a sample of gas in a cylinder of known weight and volume at flowing conditions of temperature and pressure, we can weigh this sample and determine its density. Since a gas which is compressed has a higher density than that calculated from Boyle's law, we can compare this density with the density of the gas at atmospheric pressure and determine the super-compressibility factor (Z), but the density of the gas at atmospheric pressure must be calculated from a hydrocarbon analysis of the high pressure gas.

$$Z = \frac{\text{Density Calculated from Analysis}}{\text{Actual Determined Density}}$$

Then, again we can apply the correction factor as before, where

$$F_{pv} = \sqrt{Y} = \sqrt{\frac{1}{Z}}$$

The determination of the F_{pv} factor and also the F_g factor by this method, involves a hydrocarbon analysis together with a density determination. Both the equipment and time consumed are expensive. Where an operator is buying gas from a lease, laboratory expenditure for these determinations could actually amount to more than the gas is worth. For this reason, in such cases, the economics of such precision should be considered carefully and the procedures adopted should be agreed upon by contract. The parties concerned could determine the probable magnitude of all errors and decide upon some desirable optimum precision.

In studying the behavior of a complex hydrocarbon mixture from the phase diagram, we readily agree that for proper measurement only those pressure drops over which we have no control, are to be tolerated. For that reason we should install chokes for pressure regulation on the downstream side of the orifice meters.

In some locations, it is desirable to use subsurface chokes down inside of the tubing. Any cooling effect which would cause freezing is thus taken care of by the high formation temperatures. Heaters in the flow line are in this way eliminated unless the pipe after leaving the well head is exposed to low atmospheric temperatures. Subsurface chokes can be installed or removed by the use of a special tool fastened to the end of a wire line which is lowered down through the Christmas tree.

Surface chokes are either of the positive or adjustable type. A positive choke is nothing more than a smoothly bored nipple of a definite inside diameter. They are placed right in the flow line from the well and are easily removed or replaced. An adjustable choke is a very large needle valve with a lock nut for holding it to a definite opening. This type of choke is very well suited to regulate a flow of gas which will be variable.

It is good practice to have one choke, either a positive or adjustable, right at the Christmas tree and another downstream from the meter. The first choke is a safety precaution and is of sufficient size to cause no pressure or temperature drop at the desirable flow rates but would keep the well from flowing wide open in case of a break somewhere in the flow line away from the well. The second choke then serves to regulate the actual flow of gas from the well. It may or may not be necessary to install a heater, depending upon how large a pressure drop is allowed on the gas.

Curves showing the resultant refrigeration effect due to pressure reduction of a gas are available. They have been compiled from actual experimental data and serve very well in determining whether or not heaters are necessary. They can also be used to estimate the size of heater necessary.

METER INSTALLATIONS

The meter installations for dry gas are of the conventional type. In only a few cases where extreme weather conditions prevail, hydrate freezing is experienced but this can usually be eliminated by seal pots filled with either water anti-freeze solutions, or water glycerine solutions. The latter seems to work well where rather sudden pressure changes might blow the liquid from the seal, the only advantage being in an increased viscosity of the sealing liquid.

Where a gas carries only a small volume of entrained liquid and is warm enough to prevent freezing, we have installed small traps in the meter connections. These traps contain no sealing liquid and serve only to catch entrainment and keep it out of the mercury chambers of the meter. If a gas carries a considerable volume of entrained liquid, the meter installations are more complicated. Traps of sufficient size to catch all of the entrainment would be too large. Seal pots are thus installed to keep the distillate and salt water out of the mercury chambers. These pots are filled with some suitable fluid.

A drawing of a meter installation for such a condition is shown in Figure 5. The seal pots should be of such size that the sealing liquid level will not vary more than ¼-inch. Connections should be of ½-inch pipe. Horiztonal pots seem to hold the sealing fluid better because the up-and-down movement is less for a given pressure change across the orifice. Wells which slug liquid material cause sudden pressure changes and large horizontal pots seem to be the best solution for this problem.

On several of our wells, we have built small houses which extend down to the ground, completely surrounding the meters, harness and flow line. Freezing trouble was experienced previous to the housing, and by the use of the house, we were able to eliminate seal pots. Traps to catch entrained liquid were all that was necessary.

In measuring wet gas around 2500-3000 pounds per square inch, temperatures of less than 70-75° F.

cause trouble. It is rather difficult to determine the exact point from curves of the type published by Hammerschmidt[7] and by Deaton and Frost[8], the pressure range of these curves being too low. Liquid entrainment, both distillate and salt water, render it difficult to determine the exact point of hydrate formation. Again, it should be mentioned that the best way of eliminating hydrate formation is to eliminate choking between the well head and the meter and thus utilize the heat of the formation. In all of our installations, we utilize vertical runs with the necessary length of straight pipe above the orifice flange. This pipe contains straightening vanes meeting the A.G.A. requirements in Gas Measurement Committee Report No. 2. The greatest dimension (d) of the inside cross-section of the passage through the vanes shall not exceed one fourth the inside diameter (D) of the pipe. The length of the vanes shall be at least ten times the dimension (d). Whether or not these sized vanes are best suited for gas measurement in the presence of liquid is not for us to say. If any experimental work is carried out where the actual impingement of the liquid particles against the orifice could be seen, a different type or sized set of vanes might be recommended. We have done no work on this subject and can, at this time only refer to the above specified vanes. These vanes will not only serve in assuring viscous flow of the gas as it approaches the orifice, but also would disperse entrained liquid and cause it to impinge upon the orifice in a finely divided state. We feel that the harmful result of entrained liquid is minimized by these vanes.

In vertical meter runs, all liquid will pass the orifice and be carried on through the line. A procedure similar to that employed in wet-steam measurement might yield satisfactory results in horizontal runs. A weep hole at the base of the orifice plate permits the passage of the liquid without allowing it to build up in the line above the plate. The selection of the proper size weep hole, however, is somewhat of a problem in this type of meter run. If the weep hole is too large, enough gas could possibly pass through it to result in an overall error of measurement greater than by eliminating the weep hole. On the other hand, if the weep hole is too small, liquid will bank up against the orifice plate. Vertical meter runs, therefore, seem almost the only solution.

Special emphasis should be placed upon the importance of having a leak-proof system in the meter connections. Any leak, however slight, results in the formation of ice. The constant freezing and thawing can change the differential on the meter reading. This is especially true with respect to the packing gland around the pen arm shaft.

The authors wish to express their appreciation to Mr. A. F. Benson of American Meter Company and to Mr. S. E. Buckley of Humble Oil & Refining Company for their helpful suggestions and to the Humble Oil & Refining Company for permission to publish this paper.

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(1)---Safety Choke
(2)---Straightening Vanes
(3)---Orifice Flange
(4)---Seal Pots
(5)---Orifice Meter
(6)---Flow Regulating Choke

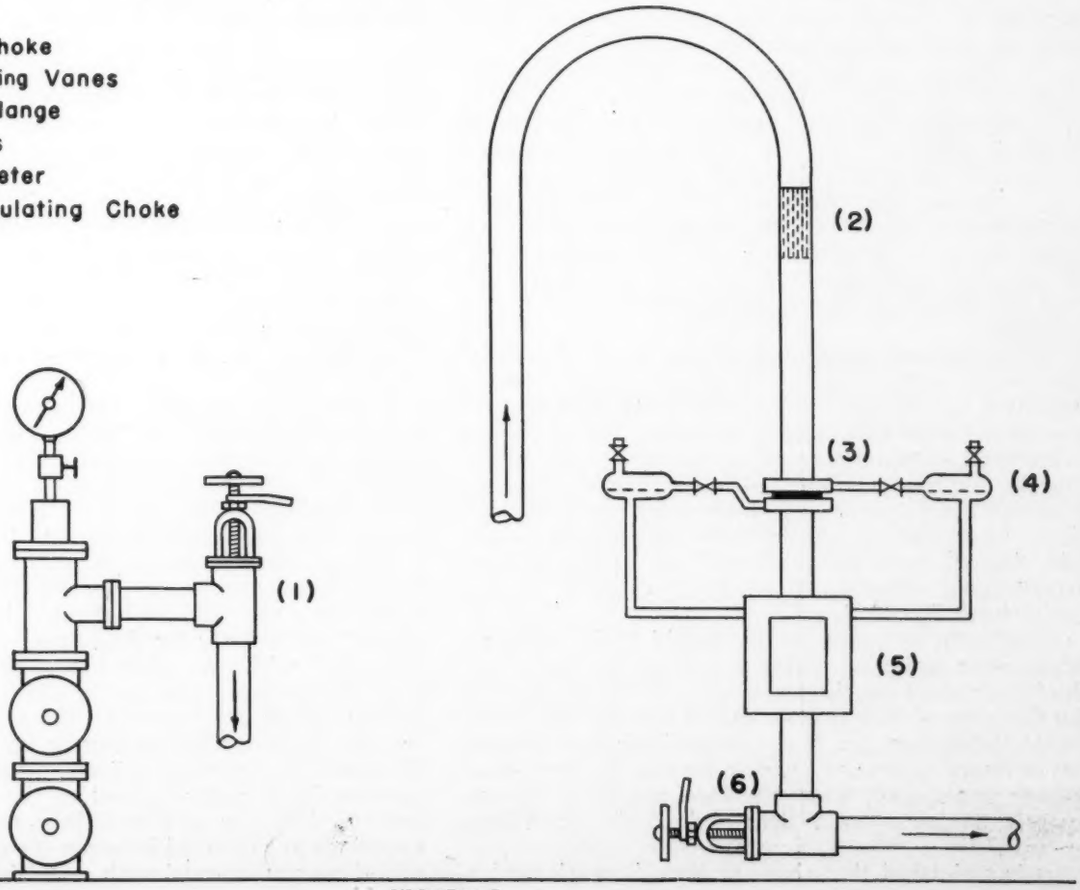

FIGURE 5

Individual Automotive Type Engine Drives in Gasoline Plant Service

UNTIL about two years ago, Skelly Oil Company used line shaft drives for auxiliary equipment in gasoline plants not provided with electric machinery. At about that time, experiments were conducted with small automotive engines, attached principally to stand-by water pumps to determine if this type of power could be successfully used in plant service. The first installations were made in the company's Fairfax, Oklahoma, No. 1 gasoline plant, using a V type eight-cylinder motor as a stand-by in the auxiliary room, and another of the same type attached to a centrifugal water pump to take the load during excessively warm days when insufficient water passed over the cooling tower with the regular equipment.

When the two engines were first installed jacket cooling was furnished with water flowing from the centrifugal pump attached to the engine, but the accumulation of scale quickly fouled the small water ports in the heads, which caused difficulty in removing engine temperature. Water in the plant was treated to remove scale that might damage large engines, with large water courses, and was sufficiently free from mineral matter that little accumulation was encountered in the large machines. But with the small engines, turning up to about 1750 r.p.m., heating of the small parts was much more rapid and this resulted in cracked jackets and heads.

To correct the difficulty, individual cooling systems were installed, consisting of galvanized radiators and using the usual type of fans to furnish air passage through the fins and around the tubes. Certain minerals and chemical combinations in the water caused rapid corrosion of the galvanized units which were soon discarded and replaced with copper alloy and brass cooling units, with a small amount of chromate in the cooling water to prevent rusting and to inhibit corrosion of cast iron parts in the engines.

After running these engines for some time with governors set to maintain speeds approximating standard centrifugal pumps with some difficulty encountered with low output of water, the governors were set to a maximum of about 1800 r.p.m., allowing the engines to deliver sufficient speed that pumps handled rated volumes of water. So long as water is supplied to the suction of these centrifugal pumps, the engines turn up to about 1700 r.p.m., with no overheating observed since large capacity cooling units were installed.

Originally designed to use liquid fuels, these engines were equipped with gas carburetors and obtain fuel from plant gas lines and are operated exclusively on this type of fuel. It is estimated that the equivalent of 15 cubic feet per housepower hour is consumed in ordinary operation, which results in economical power generation, when the load averages approximately 35 horsepower delivered to the centrifugal pumps.

It is estimated that these motors do work equivalent to about 38 miles per hour, assuming that they were pulling an automobile over average type of roads. One unit has proved so satisfactory in water pumping service that it is operating continuously throughout the full 24 hours.

Oil-bath air cleaners are used on these engines to remove abrasives from carburetor intake, which, evidently has been a contributing factor in obtaining satisfactory service. Lubrication of these motors has been given thoughtful attention, using the recommended SAE grades of premium motor oils, which is filtered continuously through a fullers earth-filled reconditioning unit. These units are mounted on the skid bases of the engines, attached to the usual oil filter lines, and reconditioned as frequently as necessary with new filter units inserted in the filter cases. A V type engine driving one of the centrifugal pumps has been operating without crank case drain, it is asserted, since July, 1937, adding oil only as the oil level falls below the full mark on the gauge stick.

After the individual gas engines had demonstrated their efficiency in plant operation, several others have been installed at various plants in Oklahoma and in the Texas Panhandle. The water station that handles all plant and cooling water for two plants in Osage County is furnished with automotive type gasoline/gas engines and delivers uninterrupted service in this type of operation. At this company's No. 2 Fairfax, Oklahoma, gasoline plant, absorption oil is circulated through the plant with a rotary pump driven by a six-cylinder motor of popular manufacture, but as the pump operates at comparatively low speed, the engine is not called upon to turn-up to above 850 r.p.m. In this same plant, two additional units are installed which are attached to centrifugal water pumps for stand-by service. One engine operates when necessary, a 2000 g.p.m., 8-inch water pump, designed to turn up to 1455 r.p.m., while the other unit handles a 6-inch pump, designed to deliver 1000 g.p.m. at a speed of 1450 r.p.m. with a head of 65 feet.

These three engines are equipped with upper cylinder lubricators, oil filters and over-speed governors, with air cleaners on the carburetor intake and equipped with gas carburetors to take fuel from the plant piping on the same delivery system as the large, slow-speed engines used to handle gas.

The engines as operated in these plants are obtained from authorized distributors of automotive equipment, and mounted on skid bases that are arranged particularly for the engine that is to be used. Together with the skid bases and radiators, the engines are assembled in the plant, attached to the pumps which are necessary for service in handling circulating water for cooling or for absorption oil in the gasoline recovery system. Pumps are obtained without bases and attached to the engine assembly units by building up the skids as necessary. Flexible couplings are inserted between the engine and pump, and these are covered with metal housings.